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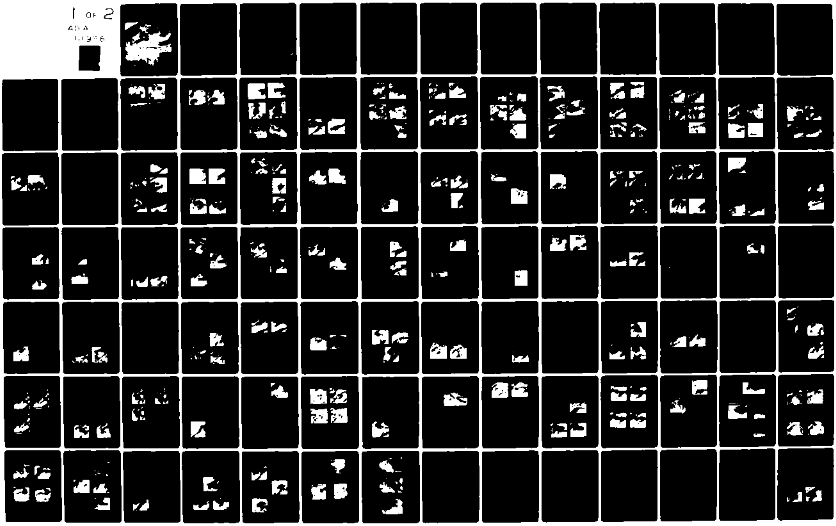

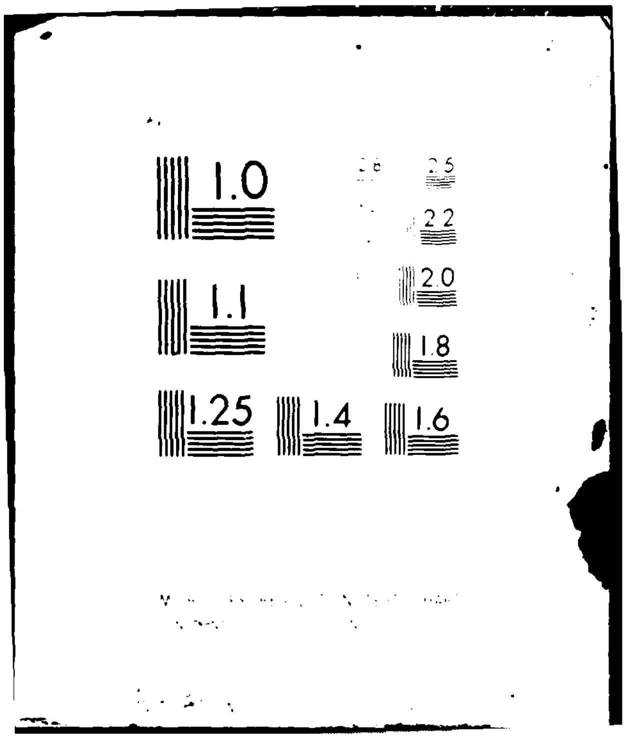
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THIRD WEATHER WING

3WW/TN-81/001

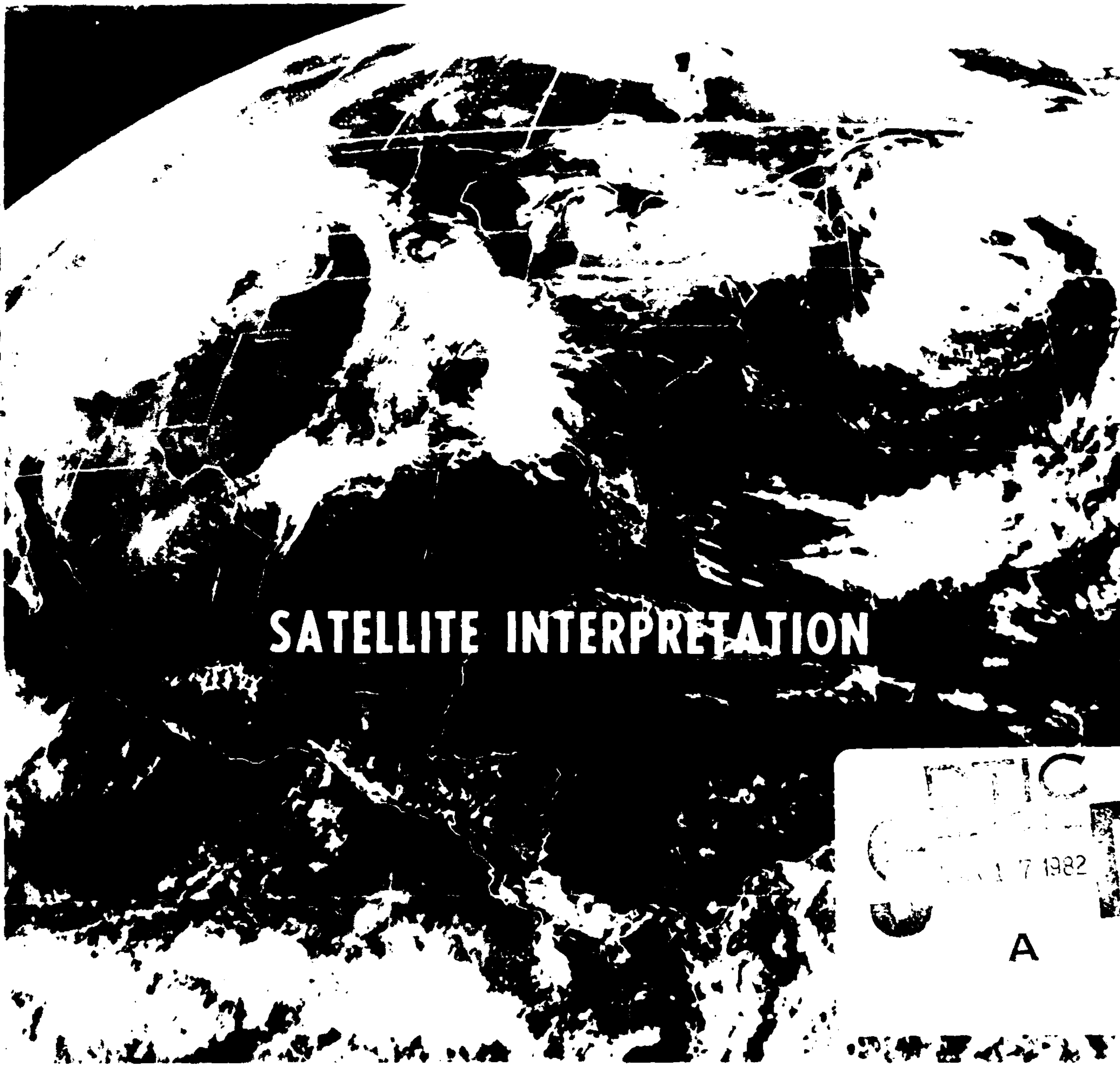
TECHNICAL NOTE

28 DEC 1981

EUGENE M. WEBER

STEVEN WILDEROTTER

THIRD WEATHER WING OFFUTT AFB NE 68113



SATELLITE INTERPRETATION

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FOR THE COMMANDER

Michael T. Schwitters

MICHAEL T. SCHWITTERS, Lt Col, USAF
Chief, Aerospace Sciences Division

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This Technical Note describes cloud formations as seen on enhanced infrared and visible GOES satellite photographs and attempts to relate the meteorological causes for these formations. Some of the latest techniques developed by NESS have been included. This Technical Note is designed to be used as a base reference for comprehensive training in the analysis, interpretation, and application of satellite data in making forecasts.

ACKNOWLEDGEMENTS

This Technical Note is dedicated to all of the men and women of the Third Weather Wing whose efforts obtained satellite equipment and trained our forecasters to use the data.

Special thanks and credit to Mr. Roger Weldon of the National Environmental Satellite Service for use of his Satellite Course Notes and consultation, to Mr. Stephen P. Weaver of the 3350th Technical Training Group, Chanute AFB, to Major Frank Wells of Air Force Global Weather Central and to the co-author, 1Lt Steven Wilderotter, Det 17, 9WS. To Lt Col Mike Schwitters and Major Al King for their consultation and editing assistance; to Mrs. Judy Money, Mrs. Carol Odom and A1C Kelly Dean for assistance in typing and layout and to A1C Joe Covert for his assistance with the illustrations. Also, I wish to acknowledge the specialized photographic assistance provided by the 3902/OTCP and 544TMS at Offutt AFB. Finally, I acknowledge, with my deepest appreciation, the perseverance of my wife, Doris, for the many hours that I spent at home in producing this TN. Her understanding nature and encouragement are largely responsible for this success.

Eugene M. Weber

EUGENE M. WEBER, CMSGT, USAF

Cover Photograph: Omaha Tornado: May 6, 1975

Shortly after this photograph was taken, Omaha, Nebraska was devastated by a tornado and 3 to 4 inch hail. Numerous tornadoes struck other locations spread along this system 1,500 miles length. Photo courtesy of NESS Applications Laboratory.

PREFACE

Having spent nearly a year actively working to obtain satellite data and training our forecasters to use this data, we determined that a need existed for a publication to be used as a standard reference. It was our desire that the most recent findings in the field of satellite interpretation be included along with the meteorological reasoning leading to those findings.

Inspired by a unit training reference constructed by Lt Wilderooter of Det 17, 9WS, Ellsworth AFB, we set out to accomplish a publication for use throughout the Wing. Publications from NESS, AWS, and other meteorologists were researched, thousands of satellite photographs were reviewed, and case studies selected. As each section evolved, NESS and AWS experts in satellite interpretation were consulted to ensure that the meteorological logic was correctly applied.

While this Tech Note is not a training program, we feel it is the most comprehensive and up-to-date reference in the field and should be used as the basis for forecasters training in meteorological satellite interpretation training.

TABLE OF CONTENTS PAGE

LIST OF ILLUSTRATIONS

ILLUSTRATIONS (Continued)

ILLUSTRATIONS (Continued)

ILLUSTRATIONS (Continued)

INTRODUCTION

This Technical Note contains an orderly discussion of meteorological logic applied to the latest techniques in satellite interpretation. Nearly 300 photographs were selected to illustrate the concepts covering the entire range of forecasting and analysis.

Our goal in the publication is to make one reference available which teaches forecasters about the things they see on the photographs and explains their meteorological causes.

We hope to update the Technical Note as new developments occur in this rapidly expanding field.

SECTION I: General Considerations When Viewing
Satellite Data

There are several considerations to make before you attempt to interpret satellite photographs. Some of these are:

- The resolution of the picture
- The frequency range of the light sensor (Visible or Infrared (Ir))
- The time of day
- The sector in which picture was taken
- The location and terrain
- The season of the year

Remember that the satellite looks down at clouds. Because of this, higher clouds may obscure the existence of lower clouds. Surface observations should always be used in conjunction with satellite data.

Two primary considerations when interpreting a satellite photo are resolution and frequency range. Were either the visible or infrared (IR) light regions scanned by the satellite? The GOES resolution within the visible range is 1, 2, 4 or 8 kilometers before it is treated by the computer for release to the users. The infrared sensor only has a resolution of 8 km. The visible sensors scan the radiation transmitted from the earth between .4 and .7 microns. This is the same range in which the human eye is sensitive. Infrared sensors scan the radiation emitted from the earth between 10.5 and 12.5 microns. The amount and frequency of the radiation emitted from the earth in the IR region is entirely dependent upon the temperature of the emitting body. A normal GOES tap infrared picture would show the coldest, highest tops white, and the warmest, lowest returns *black; this is shown in the upper half of Figure 1.* However, the computer can invert the gray scale, i.e., cold returns become black while warm returns become white; this reversal of gray scale is shown in the lower half of Figure 1. Next, the computer enhances the data. *It divides the temperature scale into sections, then assigns a* different black gray white shade to each temperature range. Normally, these shades are not in a linear progression from black to white, but jumps shades as noted by the arrows in the IR picture, Figure 2.

The gray scale used with the specific enhancement curve in the IR photo is always shown immediately below the legend data at the top of the picture (Figure 2). The scale varies with different enhancement curves. Another gray scale is located above the legend data and depicts the linear black/gray white scale. This scale appears on both visible and infrared GOES pictures.

Returning to the gray scale below the legend (enhancement curve: Figure 3) each step on the scale represents a 10°C temperature range. On the far left hand side of the scale, the temperature is +50°C with the temperature at the far right always being -100°C. In Figure 3, 0°C can be found by the tick mark immediately to the right of the resolution-enhancement curve designator - in this example - 2MB. Incidentally, the most common infrared enhancement curve used is MB.

Two problems which affect the picture within the frequency range of infrared data are: *attenuation* and contamination. Attenuation is the loss of energy due to scattering and absorption of energy (Figure 4). Attenuation causes the IR image to appear brighter (colder) than it really is. The satellite viewing angle greatly affects attenuation, with the points farthest from the satellite having the most attenuation (See Figure 4).

Contamination subpoint occurs when the satellite, which is able to see through a thin cloud deck, allows some of the radiation to come from a warmer, denser layer of clouds below. An example of contamination is thin cirrus over a low-stratus deck which gives the appearance of middle clouds. This is illustrated in Figure 5 at point A. One major problem with IR is misinterpretation of a dense cirrus cloud to be a major storm system. Figures 6 and 7, visible

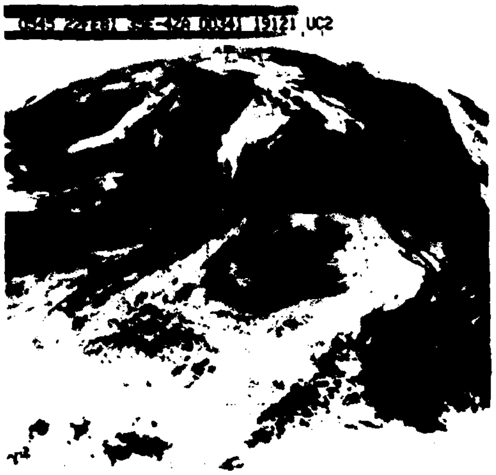


Figure 1: 0545Z 22 February 1981
Inverted Photo

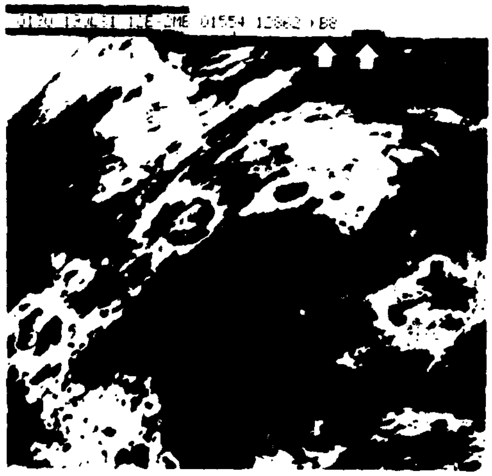


Figure 2: 0130Z 19 July 1981

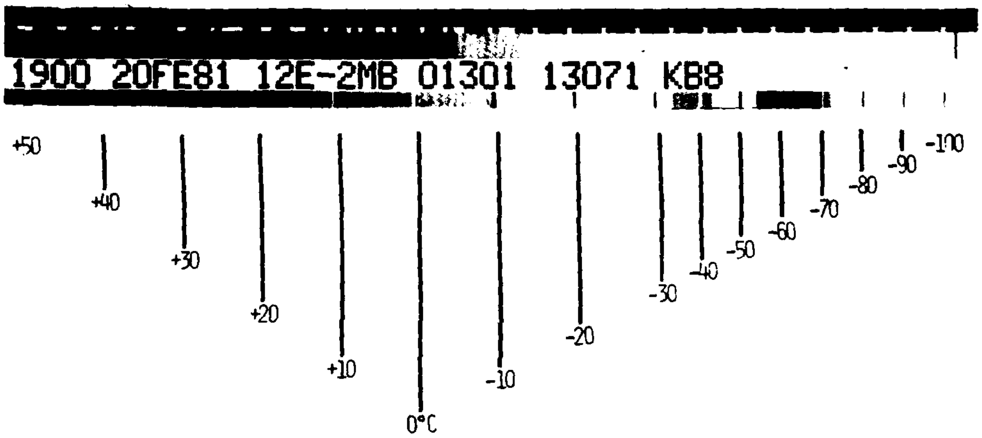


Figure 3: Infrared Satellite Photo Legend

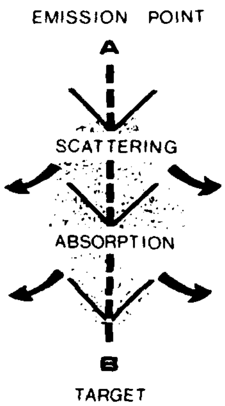


Figure 4: Attenuation

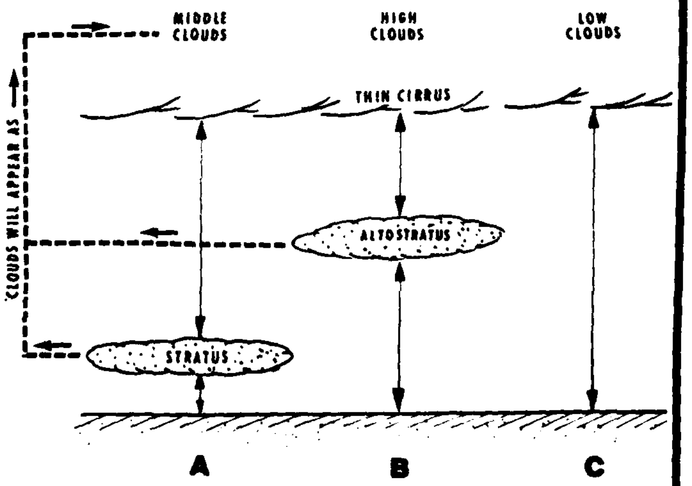


Figure 5: Contamination

and IR photos respectively, depict this misinterpretation. In Figure 6, dense filaments of cirroform clouds appear over Texas and Mexico. The enhanced IR, Figure 7, depicts several gray shades within the cirrus layer; novice satellite interpreters may believe this area to be a significant storm system.

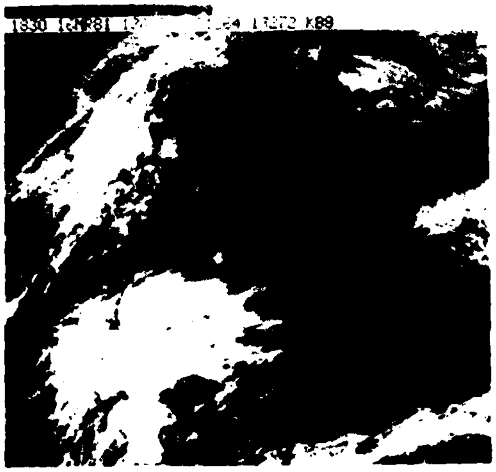


Figure 6: 1830Z 16 March 1981

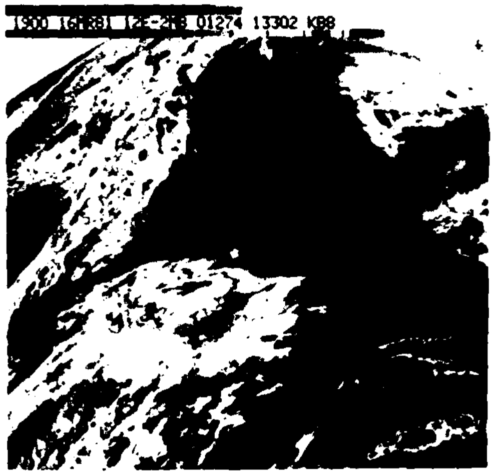


Figure 7: 1900Z 16 March 1981

The third consideration to take into account while viewing a visible photo is the time of day. If the sun is low in the sky, the picture will be darker with shadows plainly visible. These shadows help distinguish cloud layers (Figures 8 and 9). In Figure 8, a morning visible picture, note that the shadows within the storm system over the southeastern U.S. enhance the cloud tops. If the sun is directly overhead, the picture will be brighter, and possibly even have a faded appearance due to over exposure. Shadows will be hard to find when the sun is high in the sky. Figure 9, two hours later from Figure 8, illustrates the absence of shadows as the sun approaches overhead. A second example, Figures 10 and 11, shows an early morning and early afternoon photo respectively. Look especially close at the convective cloud system defined near point A in the two figures. Notice in the early morning picture (Figure 10) that the cloud tops appear higher than the afternoon picture (Figure 11) though the reverse is generally true.

A good rule of thumb to use while looking at a visible picture is the obvious: The higher and thicker the cloud, the brighter it will appear. The two major exceptions are that an early morning cloud will not be very bright, and the height of thunderstorm tops cannot be easily correlated with cloud brightness.

The fourth consideration is the sector in which the photo was taken. Data received on GOES pictures become increasingly distorted proportional to the angle that the picture was taken. Figures 12 and 13, enhanced IR photos, illustrate this problem. In Figure 12, (less distortion) the comma cloud pattern over the southern plains appears close to its true configuration. Figure 13, 45 minutes later, depicts a different sector scan which is angled towards the east and has increased longitutional distortion. Notice the distortion of the comma cloud system; it is more difficult to visualize in Figure 13 due to foreshortening.

Other considerations are: Identification of location and terrain features with respect to the season of the year. Use your basic weather knowledge to determine which clouds are likely or unlikely at a location. Do not expect mountain wave activity over ocean areas or snow in the tropics during the summer.

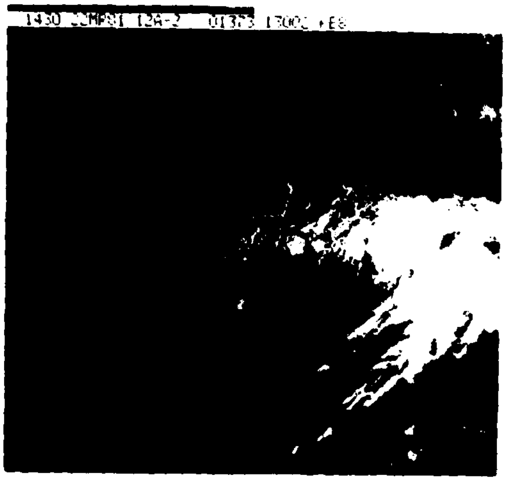


Figure 8: 1430Z 22 March 1981

Figure 9: 1630Z 22 March 1981

Figure 10: 1400Z 7 May 1981

Figure 11: 1830Z 7 May 1981

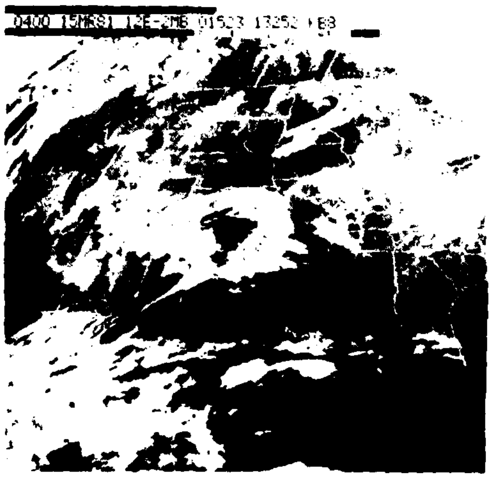


Figure 12: 0400Z 15 March 1981

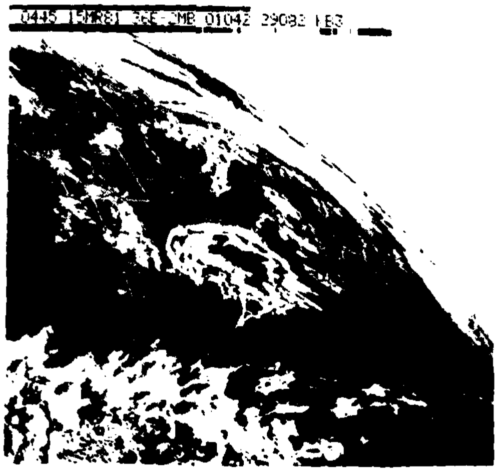


Figure 13: 0445Z 15 March 1981

SECTION 2: Identification of Cloud Types in Satellite Data

In this section a brief review of the characteristics of cloud patterns and types as shown in visible and IR photos will be discussed.

Cloud Patterns:

Synoptic events form cloud systems with various patterns. Some of the most common patterns are illustrated in Figures 14 to 17.

• Cloud Shield - A cloud shield is a broad cloud pattern which is not more than four times as long in one direction as it is wide in the other direction. A cloud shield (A) is shown across the Great Lakes and Ohio Valley.

• Cloud Band - A cloud band is a nearly continuous cloud formation with a distinct long axis where the ratio of length to width is at least 4 to 1 and the width is greater than 1 degree of latitude. A cloud band is shown at B in Figure 14.

• Cloud Line - A cloud line is a narrow cloud band in which the individual cells are connected and the lines are less than 1 degree latitude in width. Cloud lines are shown at C in Figure 15 and near D in Figure 16.

• Cloud Street - A cloud street is a narrow cloud band in which the individual cells are not connected. Several streets generally line up parallel to each other with each street not being more than 1 degree in latitude in width. Cloud streets are shown at E in Figure 15. See further cloud street discussion related to Figures 28 and 29.

• Cloud Finger - Cloud fingers develop on the forward edge of the frontal band and are often tied in a nearly-continuous fashion to the frontal clouds. These fingers generally extend in a more southerly direction than the frontal band. Figure 17 illustrates several cloud fingers, noted by the arrows, converging into a storm system located over the southeastern U.S. Cloud fingers generally end at the ridgeline.

• Cloud Element - A cloud element is the smallest cloud form which can be resolved in a satellite picture. Cloud elements are recognizable in Figure 15 within the areas noted by C and E.

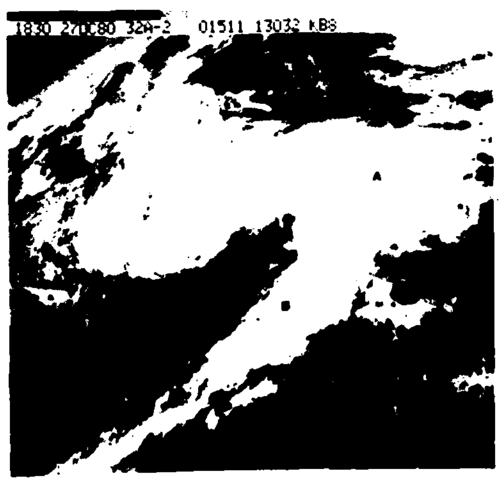


Figure 14: 1830Z 27 October 1981

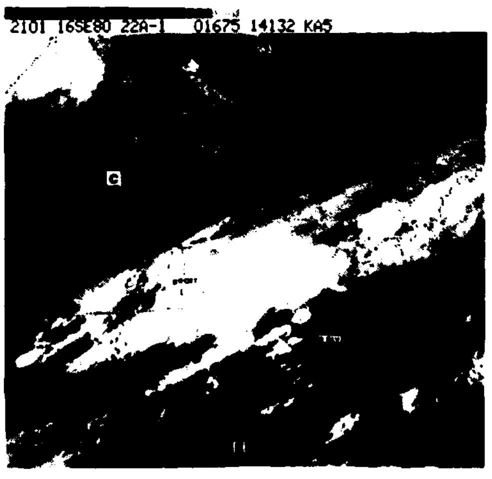


Figure 15: 2101Z 16 September 1981

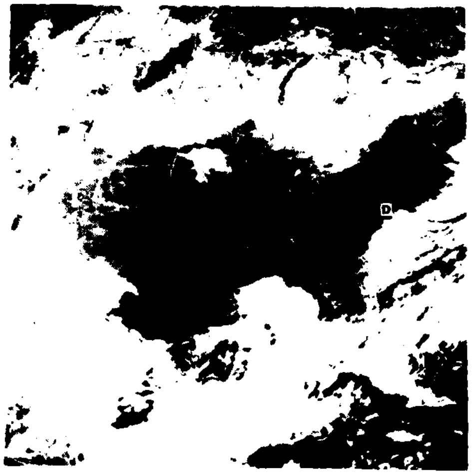


Figure 16: 1740Z 3 February 1981

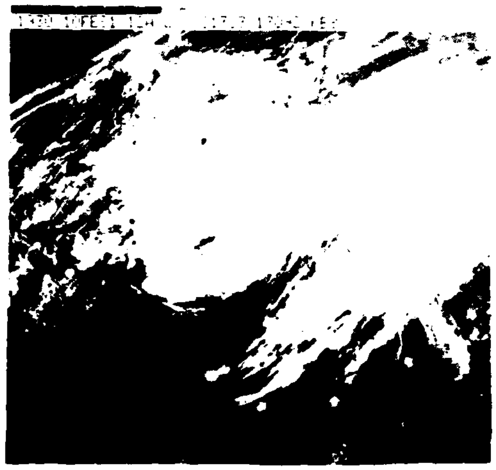


Figure 17: 1930Z 10 February 1981

Figure 18: 2015Z 2 July 1981

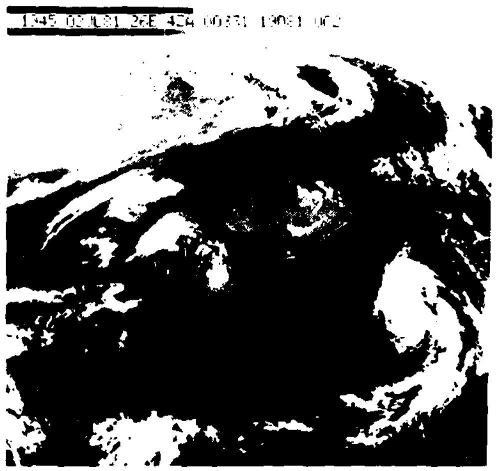


Figure 19: 1945Z 2 July 1981

Cloud Types:

Low Clouds

• Stratocumulus - Stratocumulus cloud fields appear as white, lumpy globular clouds in the visible (A and B in Figure 18) and as a consistent dull gray in infrared photos (if they can be seen at all; Figure 19). They are generally seen in closed cellular patterns with large numbers of relatively bright globular centers often connected to each other with darker, less dense clouds. As these cells continue to decrease in size, they take on a stratiform appearance and it becomes difficult to distinguish stratocumulus from stratus as shown off the California coast in Figure 20.

Figure 20: 1745Z 15 July 1981

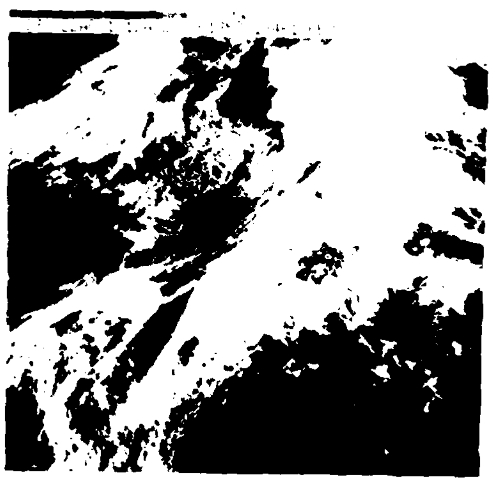


Figure 21: 20[illegible] [illegible] April 198[illegible]

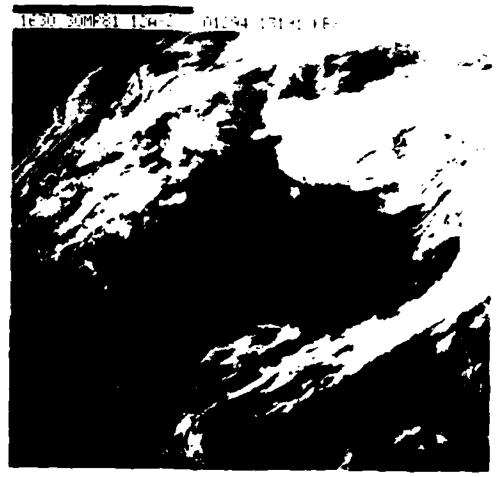


Figure 22: [illegible] March 198[illegible]

[illegible] has [illegible] often [illegible] in the northern hemisphere. The first [illegible] An example is shown in Figure 21. [illegible] This is especially common off the east coast of North America [illegible] where the [illegible] continental air encounters the warmer ocean currents. The third pattern is behind a cold front where the low clouds must start to clear as indicated by the arrow in Figure 22. It is often difficult to distinguish cold air stratocumulus from stratus such as shown in Figure 23 because the cellular size is small and appears stratiform.

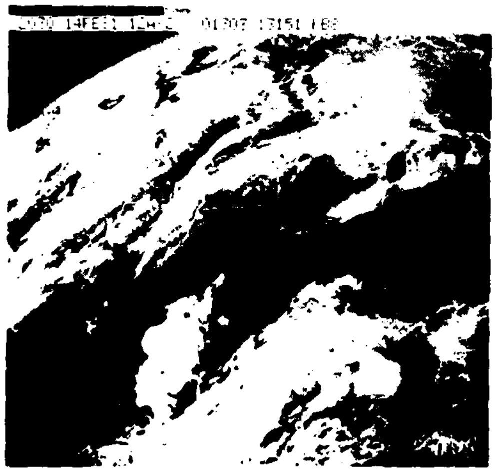


Figure 23: 2030Z 14 February 1981

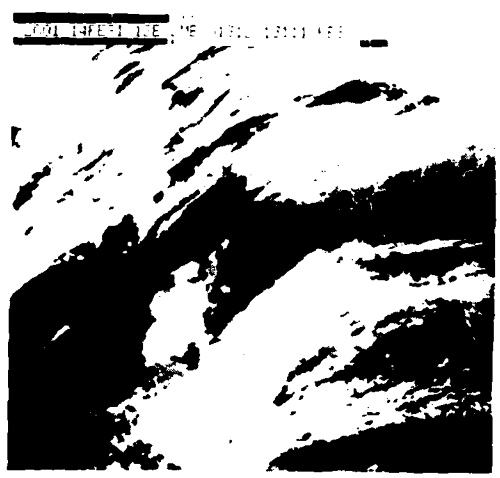


Figure 24: 2001Z 14 February 1981

• Stratus - Stratus [illegible] smooth flat texture in a visible picture as noted by the arrow in Figure 23. In the IR, stratus appears as a dull shade of gray (if they can be seen at all; Figure 24). Often, due to a temperature inversion during the cold season, the temperature of the land surface is colder than the temperature at the top of the cloud. If this occurs, it is nearly impossible to see stratus on an IR photo. Visible photos are not available during the night when many stratus events occur. Figure 25 [illegible] illustrates this stratus identification problem. In Figure 25a, a [illegible] shot, a continental polar air mass prevails across the Midwest; the center is located in western Missouri. A stratus layer exists from Texas northward into Kansas, but it is very difficult to see because of the cold terrain. The eastern fringes of the stratus layer is barely discernible over eastern Texas as noted by the arrow in Figure 25a.

[illegible]

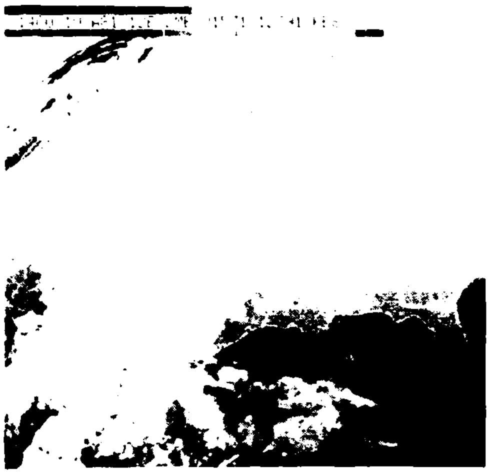


Figure 25a: 1400Z 10 January 1981

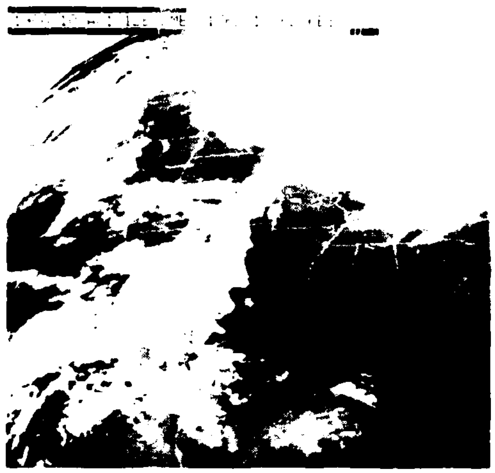


Figure 25b: [illegible] January [illegible]

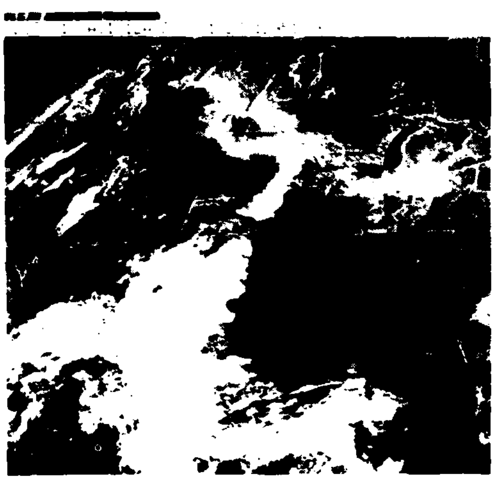


Figure 25c: 2330Z 10 January 1981

Figure 26: 1931Z 2 February 1981

[illegible] stratus [illegible] strategy [illegible] Note the [illegible] first signal [illegible] of the [illegible] A rule of [illegible] is stratus.

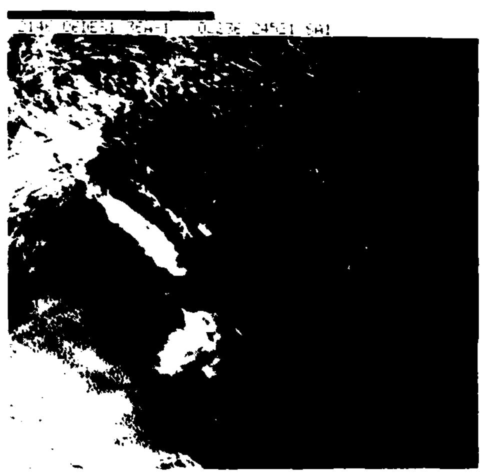


Figure 27: 2136Z 4 December 1981

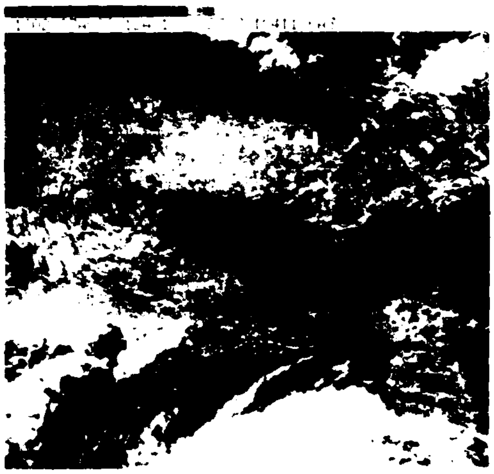


Figure 31: 1500Z 29 March 1981

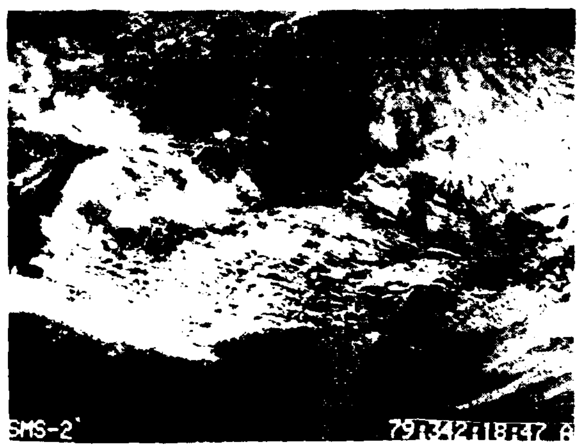


Figure 3[illegible]: 14[illegible]Z [illegible]

Figure [illegible]: [illegible]

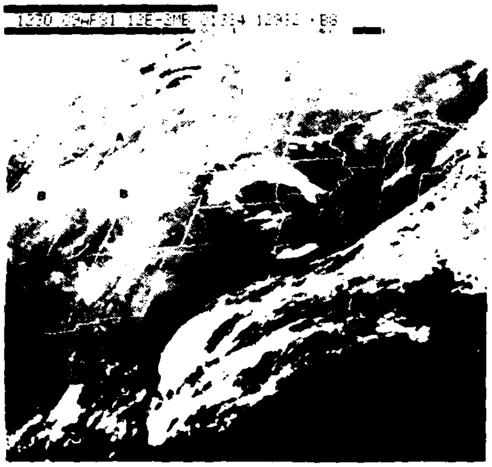


Figure 3[illegible]: 1230Z 9 April 1981

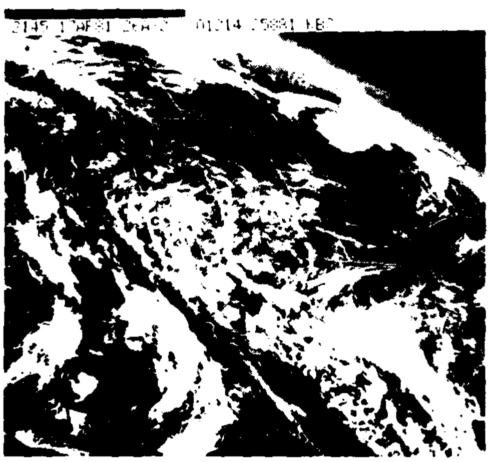


Figure 35: 2145Z 1[illegible] April 1981

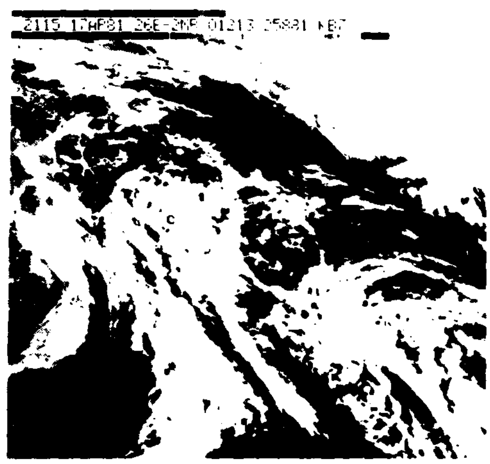


Figure [illegible]: [illegible] April 1981

• Cirrostratus [illegible] extensive sheets. In the visible, the [illegible] shades of grays and blacks reveal [illegible] tops. In Figures [illegible] respectively, a cirrostratus cover associated with [illegible] stream [illegible] Mexico and Texas. In both figures, [illegible] filaments of cirrus extending [illegible] cirrostratus layer across Texas and Mexico [illegible] the arrow. These filaments are [illegible] frequently downstream and on the [illegible] They are [illegible] with vertical shear, and [illegible] indicators of the upper level wind [illegible] generally terminate at sharp [illegible] across [illegible] latitude. In the enhancement [illegible] photo, [illegible] the exaggeration of the filaments.

Figure 37: 1930Z 25 January 1981

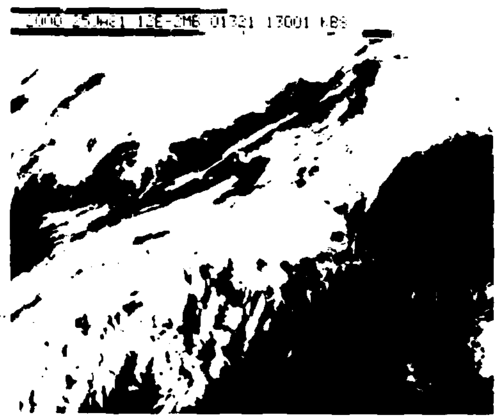


Figure 38: 2000Z 25 January 1981

Figure 39: 2032Z 3 June 1981

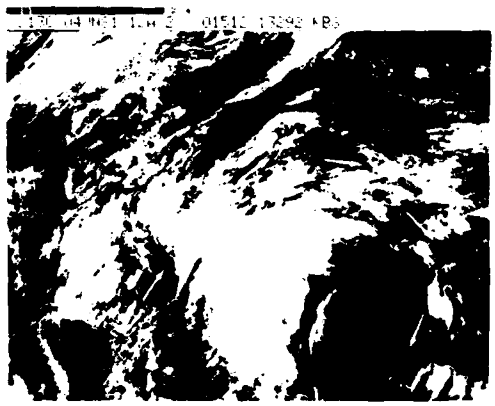


Figure 40: 2130Z 4 June 1981

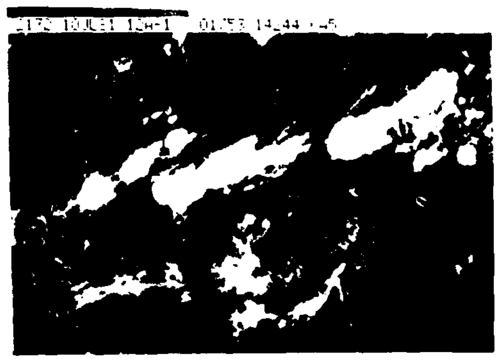


Figure 41: 2132Z 10 July 1981

• Anvil Cirrus - Anvil cirrus is blowoff from thunderstorms. Figure 39 depicts several groups of thunderstorms across the southern plains, southern Rockies and Mexico. Anvil cirrus has a very sharp upwind edge (A), and a fuzzy downwind edge (B). The anvil cirrus points out either the direction of the upper winds or the direction of the vertical shear. In Figure 39 it is apparent over Mexico (C) that the upper winds over this area are from a southwest direction. Often the blowoff from numerous thunderstorms combine to form an extensive cirrostratus shield as seen at D in Figure 39.

A second example is shown in Figure 40 where anvil tops can be used to determine the direction of the upper winds. This is shown by the long arrows in Figure 40.

• Cumulonimbus - Cumulonimbus cells may form into patterns similar to the smaller convection clouds. Each cell is circular in shape as noted across the Gulf coastal states in Figure 41. They appear white in the visible and may cast shadows on lower cloud decks. To the east of an advancing squall line, a cirrostratus shield may develop due to excessive anvil blowoff. Not all cumulonimbus cells have anvils, and their IR temperatures are dependent upon the height of the cell.

[illegible]

• Mountain-wave turbulence is indicated by leeside [illegible] through [illegible] mountain wave activity respectively over the Rocky Mountains, [illegible] Hills, and Appalachian Mountains.

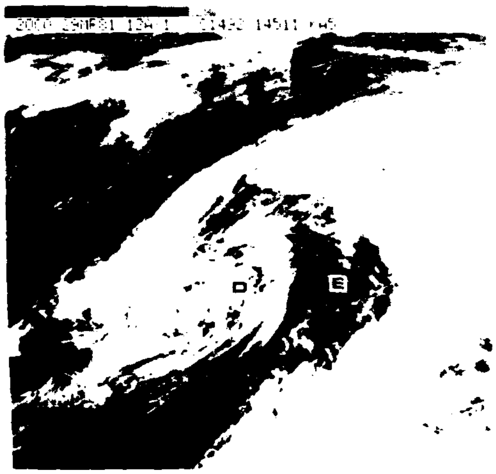


Figure 42: 2000Z 29 March 1981

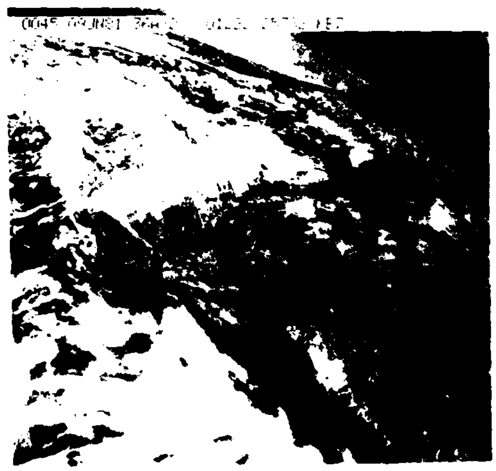


Figure 43: 0045Z 9 June 1981

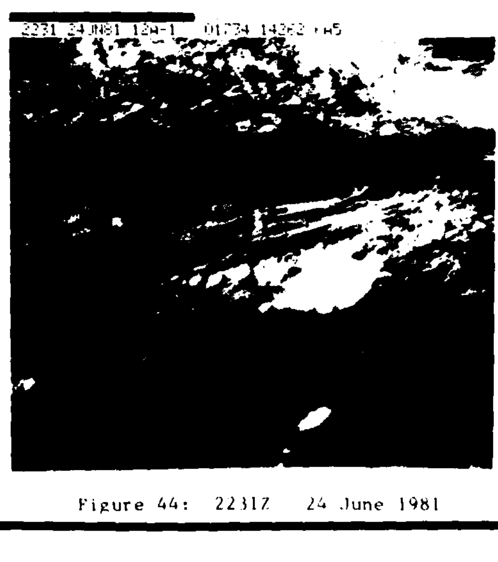


Figure 44: 2231Z 24 June 1981

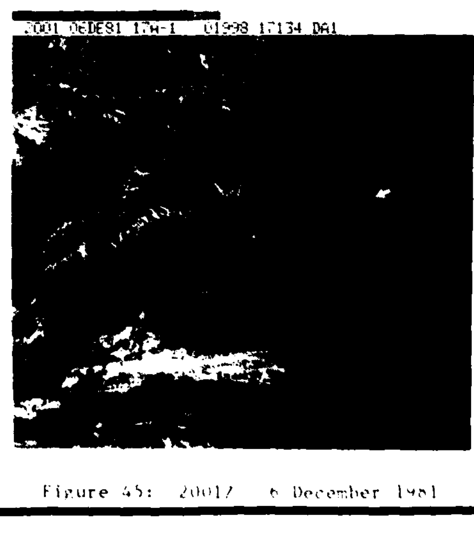
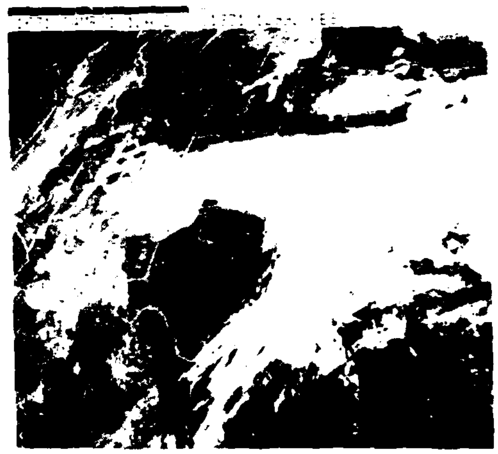


Figure 45: 2001Z 6 December 1981

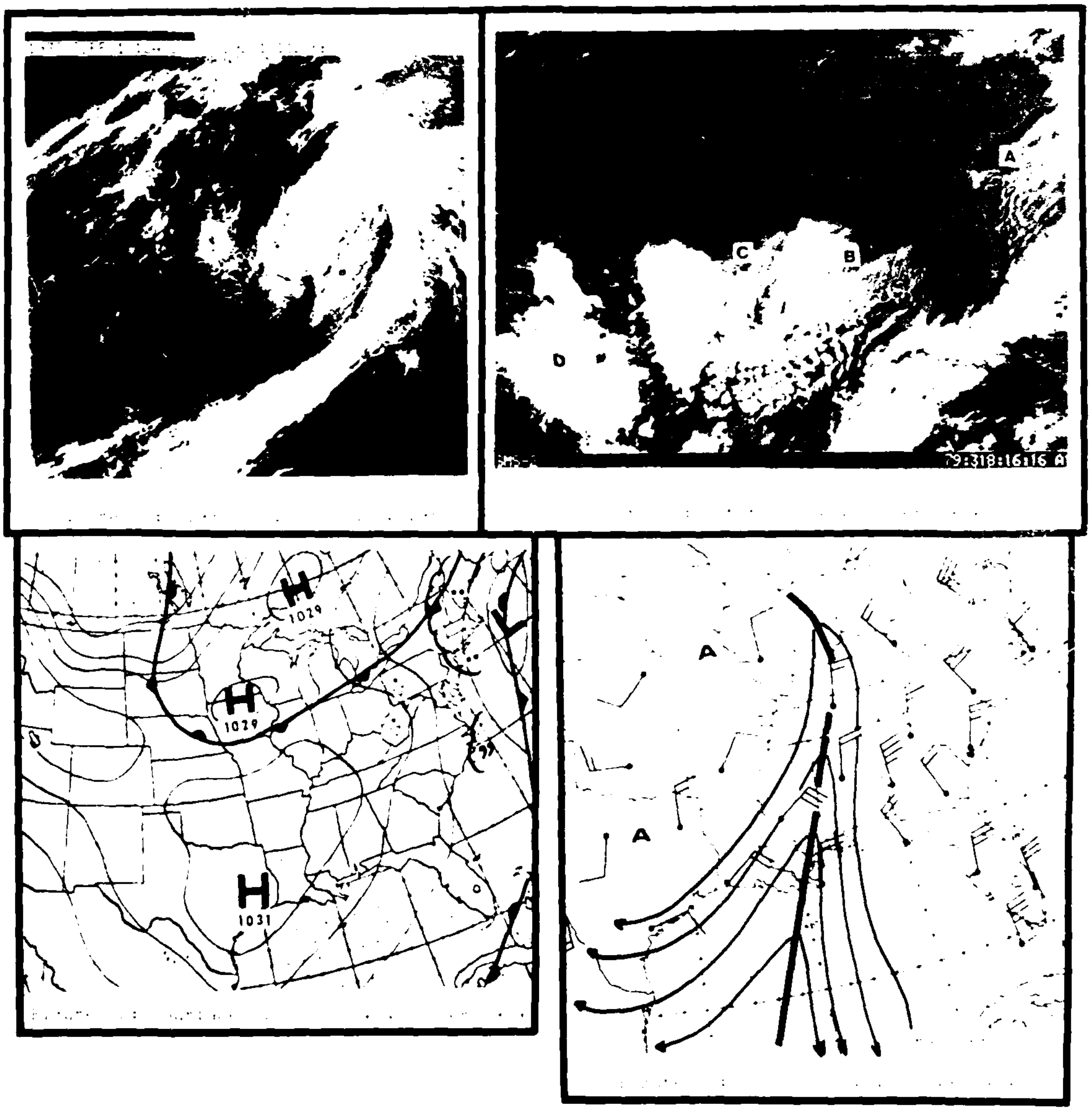
Figure [illegible]: [illegible] March [illegible]



[illegible] March [illegible]

Figure 48: 1630Z 5 March 1981

Figure [illegible]: [illegible] February [illegible]


A
C
B
D
79:318:16:16 A
H
1029
H
1029
H
1031
A
A

[illegible] ... a jet stream, the wind [illegible] ... a jet stream, the wind [illegible]

[illegible] ... than ten knots [illegible] ... greater than [illegible]

[illegible] ... the surface wind

[illegible]

[illegible] ... this technique becomes [illegible]

[illegible] Numerous cloud trails or lines can be seen in persistent marine anticyclones where [illegible] exhaust gases have seeded the [illegible] stratocumulus and caused an overcast [illegible] (Figure [illegible]). These trails will persist [illegible] for days in areas of light winds.

[illegible]

[illegible] can be estimated from satellite [illegible] the following methods:

- [illegible] - If the anvil continues to remain about the same size as the [illegible], then the upper winds are light. If the anvil is about double the size of the [illegible], the [illegible] is approximately twenty [illegible]. If the anvil is triple the size of the [illegible], the [illegible] about thirty knots. [illegible], multiply the number of [illegible] by ten to obtain the upper wind speed.

- [illegible] - Transverse lines or bands are often observed in jet stream [illegible]. [illegible] patterns appear as small-scale lines [illegible] of the [illegible] wind [illegible] and they indicate horizontal [illegible] the wind [illegible]. These lines look somewhat like waves, but are much more irregular [illegible] and are observed over oceans as well as over land. Figures [illegible] transverse lines and cirrus filaments in jet stream cirrus [illegible]. The jet stream is generally to the left of the lines and generally [illegible] edge of the cirrus shield as shown in Figure 5B. [illegible]

[illegible] with wind speed maximums and occurs [illegible]. Transverse banding is shown near location A in Figure 5[illegible]. [illegible] in Figure [illegible] may occur equator[illegible] [illegible] information about the winds. A more specific [illegible] transverse banding will be shown in Section [illegible], Part [illegible]

- [illegible] cirrus is formed and maintained by wave motion just as lee waves [illegible]. However, they are not associated with terrain [illegible] cirrus. The winds are usually perpendicular to the [illegible]. The [illegible] for wind speed using billow clouds is:

[illegible]

[illegible] wavelength [illegible] miles.
[illegible] knots.

[illegible] using billow clouds to determine jet stream speed is that [illegible] lower clouds [illegible] the cloud wavelength.

[illegible] in the lower levels of the atmosphere.

- [illegible] - Cirrus streaks form parallel to the flow and to the right of the jet stream when there is insufficient moisture to form a full cirrus shield. They are usually observed on the backside of troughs. Winds of greater than sixty knots are usually required for their formation. In Figure 5[illegible], cirrus streaks stretch across the southern U.S. and the Gulf of Mexico.

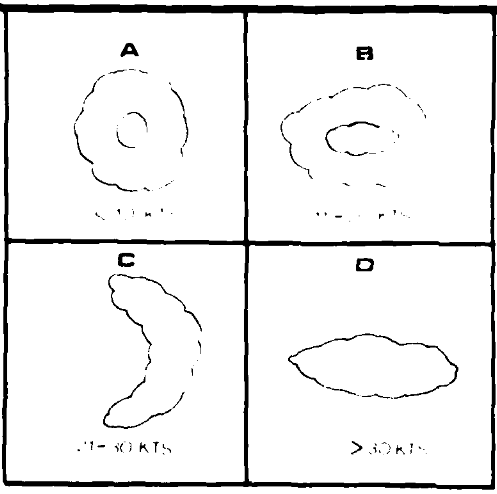


Figure 54: Open-Cell Cumulus Shapes

Figure 55: 2200Z 22 February 198.

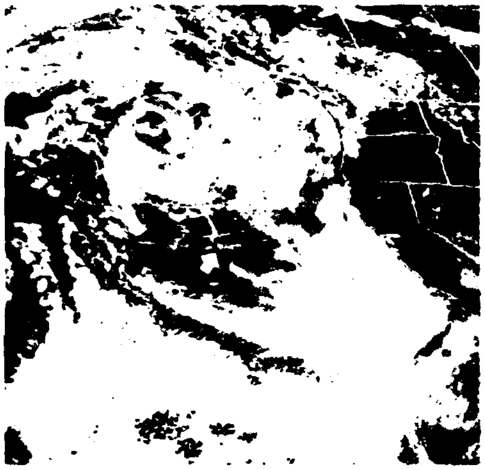


Figure 56: 1815Z 19 July 1981

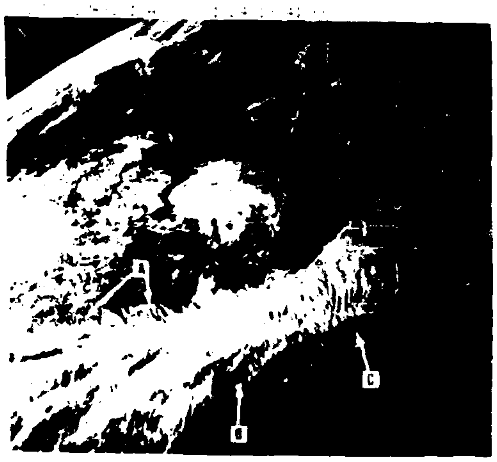


Figure 57: 2230Z 1 March 1981

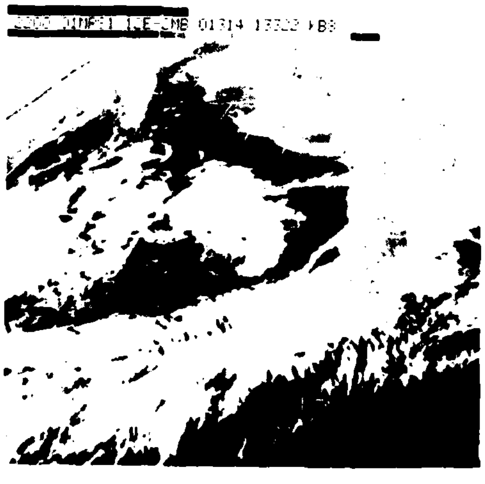


Figure 58: 2200Z 1 March 1981

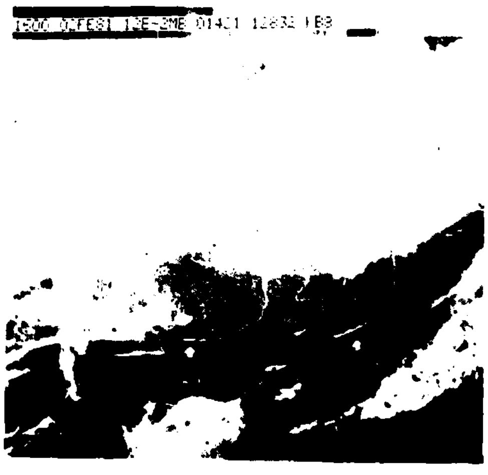


Figure 59: 1600Z 2 February 1981

Striations/Shadows:

Striations are narrow, straight or curved streaks in cloud that appear in an overcast area. Striations frequently give indications of the [illegible] of the [illegible]. A low sun angle causes highlights and shadows which produce the striated pattern. [illegible] [illegible] morning visible photos which highlight striations. In Figure 6[illegible], note the cyclonic striations over the Great Lakes area as noted by the arrows.

A second example is shown in Figure 61. Along with striations, shadows are [illegible] which gives the Great Plains storm system an effect [illegible] [illegible], separated by separate shadows, are as indicated by A, B, and [illegible] [illegible] clinic zone cloud shield, a lower cloud layer [illegible] is shown at [illegible], and the lowest layer (low clouds) appears at [illegible] Nebraska and Iowa (area C) north of the low [illegible] zones within the occluded segment of the frontal system.

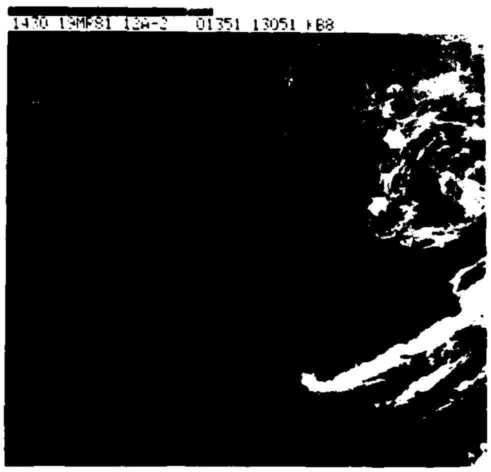


Figure 60: 1430Z 19 March 1981

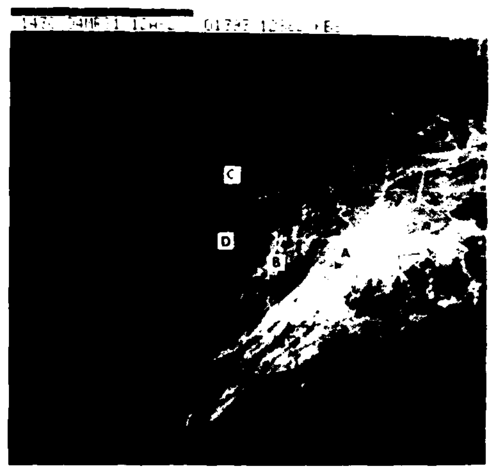


Figure 61: 1430Z 4 March 1981

Lithometeors:

Wind-driven particles such as dust, sand, smoke and volcanic ash may hide or obliterate surface features. They are characterized by a dull, hazy, filmy appearance similar to thin cirrostratus in visible photos; IR photos may or may not reveal these lithometeors.

• A duststorm event associated with a Great Plains storm system is shown over northwestern Texas in Figure 62. Surface wind directions were from a westerly component; wind speeds were reported between 45 and 50 knots. In the IR, Figure 63, the dust area is apparent and is within the same gray shade scale as low clouds located over the northern Texas panhandle and in the Gulf of Mexico.

• A large area of smoke from Canadian forest fires is shown from southern Canada across the upper Midwest to the Great Lakes - Ohio Valley area as indicated by the arrows in Figure 64. Notice how the smoke layer across the central Midwest flows into the Rocky Mountain disturbance; the smoke layer has the same inflow pattern that a cloud layer would have if present.

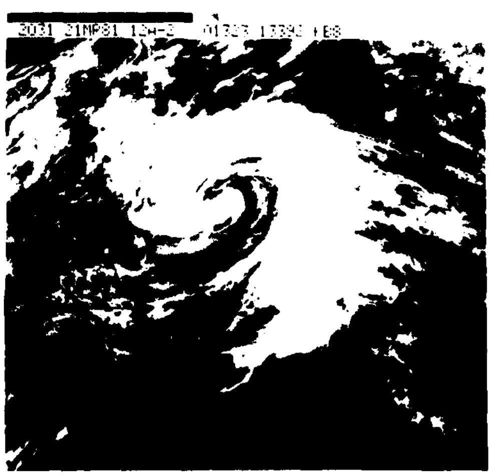


Figure 62: 2031Z 21 March 1981

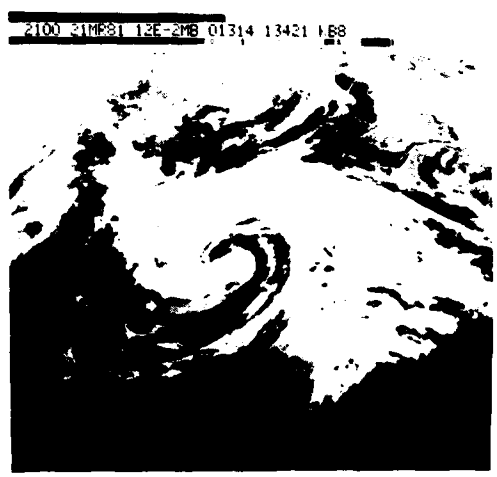


Figure 63: 2100Z 21 March 1981

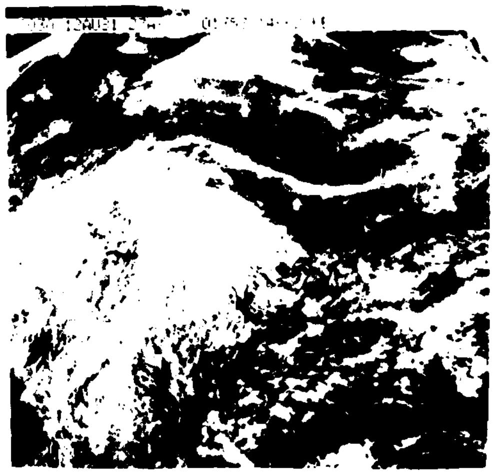


Figure 64: 2030Z 12 August 1981

Figure 65a: 0600Z 25 February 1981

Figure 65b: 1631Z 25 February 1981

Figure 65c: 1630Z 26 February 1981

Low-Level Moisture Areas:

Enhanced IR satellite pictures can provide forecasters with an additional tool for forecasting the extent of warm air advection stratus and fog at night. Frequently, areas where fog and stratus are more likely to form over or advect into will appear as relatively dark areas on enhanced satellite pictures (after Gurka, 1976) (1). These dark areas are normally found downwind from a moisture source, such as the Gulf of Mexico and appear to outline the boundary of relatively moist air in the lower levels. This boundary can be monitored and used as an estimate of the extent of nocturnal fog and stratus developement and advection. During the night, moist air absorbs the earth's radiation, becomes warmer, and reradiates this energy in all directions - part of it back towards earth. In areas not covered with moist air, the earth's radiation is loss to space. The net effect is a warmer earth in areas covered by air with high moisture content which appears darker on infrared photographs.

Figure sequence 65 shows this event. In Figure 65a, an IR, a dark area can be seen across the southern and central plains; the western boundary of the moisture area is noted by the arrows. This dark area represents a tongue of moisture advection although stratus is not evident. Stratus is occurring across eastern Texas and offshore, but nearly all of the stratus is hidden by a cirrus layer. The northern limits of the dark area extends well to the north reaching into southern Nebraska. From this IR photo, the potential for stratus formation or advection would be forecast as far north as Nebraska provided no air mass changes would occur.

The visible imagery, ten hours later, Figure 65b, depicts subsequent stratus advection. In Figure 65c, (24-hours later from Figure 64b and 34 hours later from Figure 65a) stratus has indeed, advected as far north as Nebraska and has reached into the Dakotas.

Of course, the extent of the moist air at the surface can be located with surface dew points. The satellite, however, has much higher resolution than the surface observation network.

Terrain Features:

Forecasters should not be confused in interpreting terrain as low clouds on IR photos. In Figure 66, a large grey area is shown over the Rocky Mountains (location G; a small patch of cirrus is shown over the Front Range); the gray shade approximates a layer of low clouds. The related visible photo, Figure 67, reveals that nearly all of the Rocky Mountain areas are cloudless.

A second gray shade area, which could be misleading to novice satellite interpreters as low clouds, is faintly shown across the area noted by H in Figure 66 (arrows mark the western boundary). This grey cloud-free area is cold air; it closely follows the cyclonic configuration of the cold air stratus pattern, location J, associated with the Great Lakes storm system.

Figure 66: 1600Z 23 February 1981

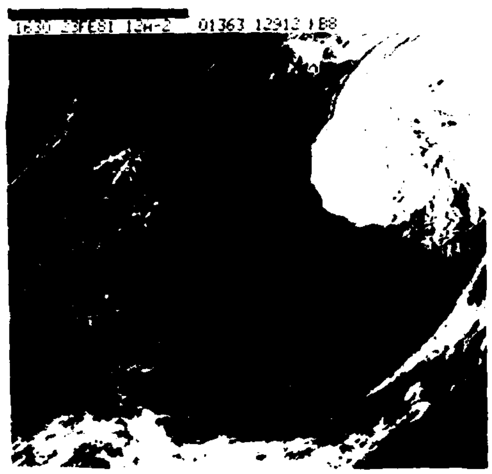


Figure 67: 1630Z 23 February 1981

Satellite Photos Courtesy of:
AFGWC
SAC RSG
DET 1, 9WS

Figures 274, 275, 276 and 277 courtesy of National Environmental Satellite Service (NESS).

All conventional analyses shown throughout this Technical Note are duplicates of either NWS's Daily Weather Maps Weekly Series or facsimile charts.

PART II

SYNOPTIC [illegible]

In Part II cloud patterns and systems related to [illegible]. Included are relationships between cloud systems and jet streams, [illegible], leafs, and comma systems. In the severe convective weather section that follows, [illegible] squall lines, outflow boundaries and intersecting boundaries will be shown. [illegible] ends with discussion on cutoff lows and tropical storm systems as seen on satellite [illegible].

SECTION 1: Locating Jet Streams

The location, configuration and velocity of jet streams and their [illegible] in the mid and upper troposphere are vital keys in the development [illegible] convective storms. Jet streams meander meridionally [illegible] "subtropical jet" have been given to these strong middle and upper level wind zones. These zones are constantly forming, dissipating, intensifying, weakening, [illegible] latitudinally and longitudinally. Several jet streams often appear [illegible] upper air analyses such as shown in Figure 68. Jet streams often split into branches [illegible] more difficult to identify these systems on satellite photos. An example [illegible] shown in Figure 69; an extensive area of jet-related cirrus and cirrostratus [illegible] the central and western U.S. (see related discussion, Figures [illegible]). This section [illegible] help forecasters locate most jet streams on satellite pictures.

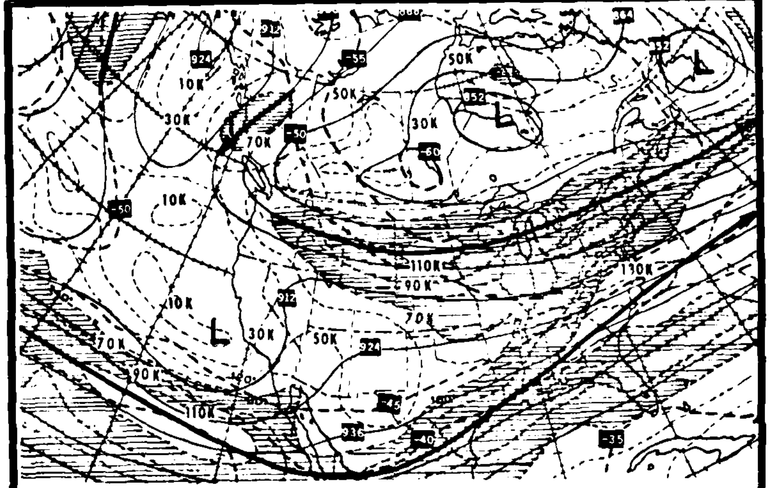


Figure 68: 300MB 0000Z 14 February 1980

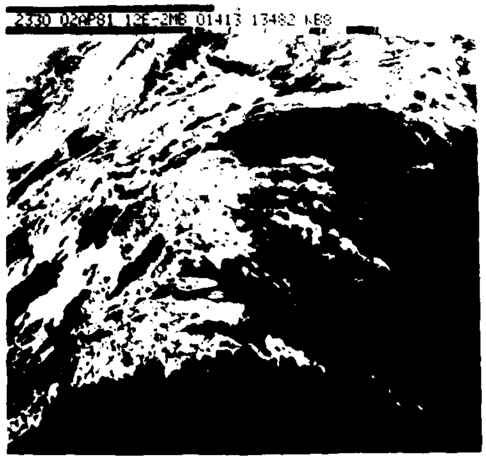


Figure 69: 2330Z 2 April 1981

Relationships Between Jet Streams and Cloud Patterns:

There are some general relationships between jet streams and cloud patterns observed on satellite pictures. If the assumption can be made that all jet streams can be identified on the [illegible] upper air analyses, then with the use of satellite data alone, jet streams can be identified about [illegible] of the time. According to Weldon, there are four rules to use as guides to determine the jet stream positions on satellite photos. They are:

Rule 1 - Cirrus cloud shields tend to form or persist on the anticyclonic shear side of the jet stream axis - with a well defined cloud band along the axis (Figure [illegible]). This cirrus shield is called baroclinic zone cirrus. Figure [illegible] depicts a baroclinic zone cirrus pattern across the central [illegible]. Axes of maximum winds [illegible] as a border between dry air on their cyclonic shear side (cloud-free boundaries; location A in Figure [illegible]) and moist air on the anticyclonic shear side (cloudy [illegible] cloud boundaries; location B). The jet positions will be about one degree of latitude north (or on the cold air side) of the cirrus shield as shown in Figure [illegible].

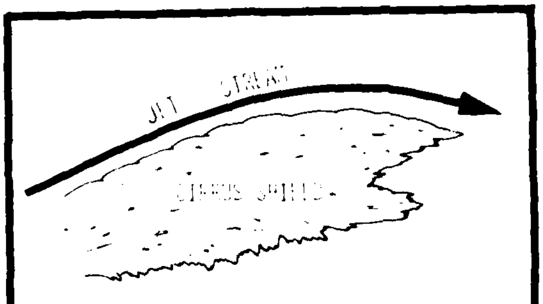


Figure [illegible]: Rule 1

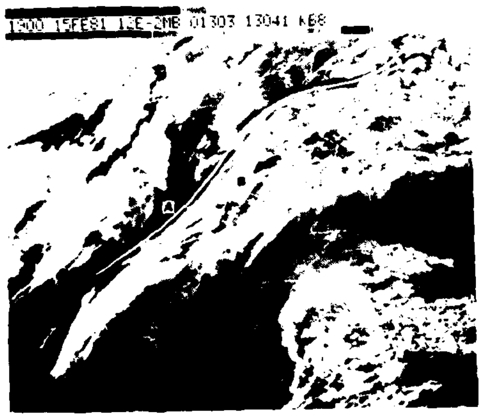


Figure 71: 1900Z 15 February 1981

Figure 72: 1330Z 22 February 1981

In visible pictures especially, the jet may be found where the baroclinic cirrus shield crosses a vorticity comma cloud system. The cloud texture goes from lumpy (lower convective clouds) to smooth (higher stratiform clouds). Figures 72 and 73 illustrate this method within a mature storm system. In Figure 72, an IR photo, a vorticity comma cloud system, noted by B, can be seen across Iowa and western Missouri behind the larger baroclinic cirrus shield (A). Focusing in on the comma cloud area in the visible photo, Figure 73, the comma head is noted at G and the tail at H. The polar jet stream can be located where cloud characteristics change from smooth to lumpy; these changes are noted by the arrows and the black line denotes the jet axis. The 500mb analysis, Figure 74, is included to show the flow pattern.

This rule locates the jet stream about 25% of the time.

Figure 73: 1430Z 22 February 1981

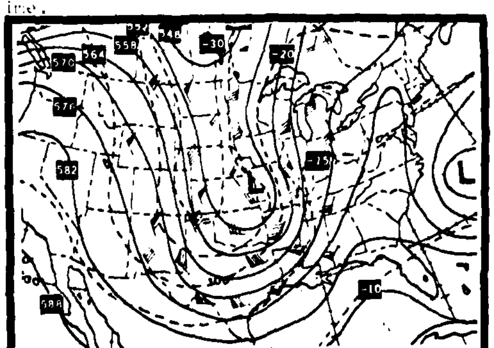


Figure 74:
500MB 1200Z 22 February 1981

Rule 2 - The second rule states that where baroclinic zone cirrus is not present (Rule 1), but other high or middle clouds are, cloud bands will be most advanced downstream where the jet axis crosses the (point A in Figure 75). The upstream borders, point B in Figure 75, are usually well defined and form a U or V shape with the axis of maximum winds in or over the slot. This pattern is generally true of many short wave systems - especially when short waves are moving through a long wave zonal pattern or on the front side of a long wave ridge (Figure 76).

This method locates the jet about [illegible] of the time.

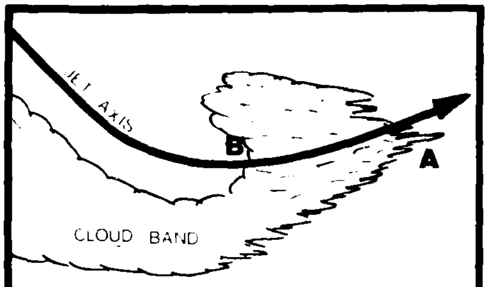


Figure 75: Rule 2

Figure 76: 0545Z 29 January 1981

Rule 3 - When no high clouds (with tops at jet stream levels) are present, the axis of the jet stream will often be revealed as a boundary or interface between different types of low-level cloud cover (Figure 77). These lower level boundaries are most commonly found over oceans where abundant low-level moisture exist (Figure 78). In the IR photo, Figure 78, a short wave comma cloud system appears over the southwestern U.S.; the 500mb analysis, Figure 79, reflects this short wave system. To the west of the comma cloud and to the north of the jet stream, a cluster of open cell cumulus is noted near point G. Further to the west, the open cell cumulus lines gradually change characteristics to closed cell stratocumulus lines as noted at H. The interface is marked by the dashed white line: the southern portion of the interface goes off the bottom of the photo. Normally, the jet stream can be located about one to three degrees north of the interface when the jet is aligned west to east as shown in Figure 77. In this particular example, however, the jet stream (aligned north to south) would be located one to three degrees to the left of the interface (looking downstream) as shown in Figure 78. (Note: In Figure 78, "P" marks the northern polar branch; "T" - the southern polar branch and "S" - the subtropical jet.)

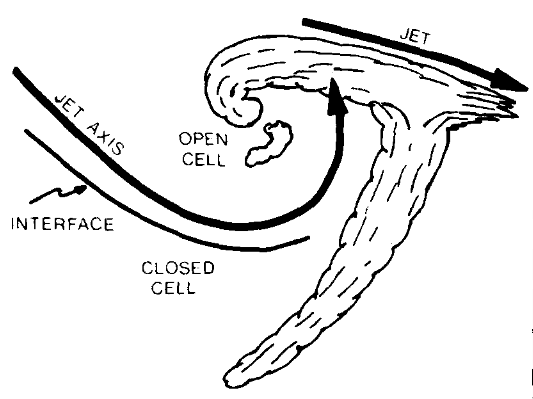


Figure 77: Rule 3

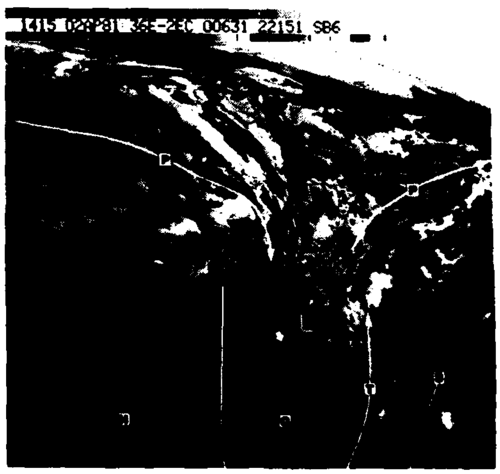


Figure 78: 1415Z 2 April 1981

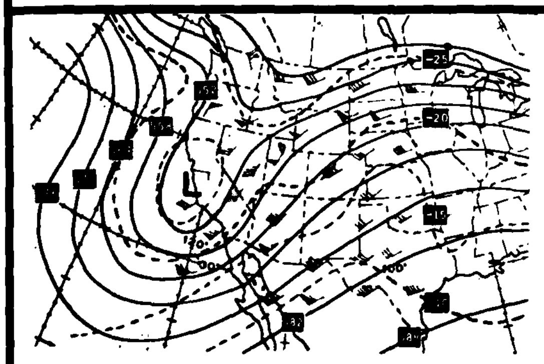


Figure 79: 500MB 1200Z 2 April 1981

The jet stream/lower cloud interface just presented are most likely to occur when the jet stream is well defined, is channeled (vorticity isopleth parallel to the contours) and is vertically deep in the atmosphere. Over land during the day, stratocumulus clouds are likely to be south of the jet with clear conditions to the north.

This rule will help find the jet stream about 25 of the time.

Rule 4 - A combination of the three previous rules will add ten percent to the accuracy rate.

The four rules just presented should help forecasters locate jet streams about 75% to 85% of the time. The remaining 15% to 20% when the jet stream cannot be located on satellite photos may be attributed to a breakdown of the relationships and rules described earlier. Several other reasons why jet stream may be difficult to identify on satellite photos are:

• There is a wide zone of strong winds, but the maximum winds are not concentrated in a narrow enough zone to be identified as a jet axis.

• The jet stream and its associated baroclinic zone isn't continuous between two segments. Often over a ridge, the air spreads and slows into a region with no well defined baroclinity (and no strong winds).

• There is not enough middle and high level moisture present to produce clouds, even though the jet stream is strong and well defined.

• High level moisture is present with a well defined border along a channeled jet axis (winds parallel to contours flow), but clouds have not formed. In such cases, cirrus will often form suddenly to the right side of the jet axis as it progresses downstream over a mountain range. A "lee-of-the-mountain" cirrus deck will form downstream from the mountain range and to the right of the jet axis as shown in Figure 80. In Figure 80, a cirrus band stretches southwest - northeast across the southern Rockies to the Great Lakes. The cirrus formation area begins over and to the east of the southern Rockies as noted by the arrow in Figure 80. The related 300mb analysis, Figure 81 (three hours earlier than Figure 80), shows the jet stream location; the cirrostratus layer lies along and to the right of the jet stream.

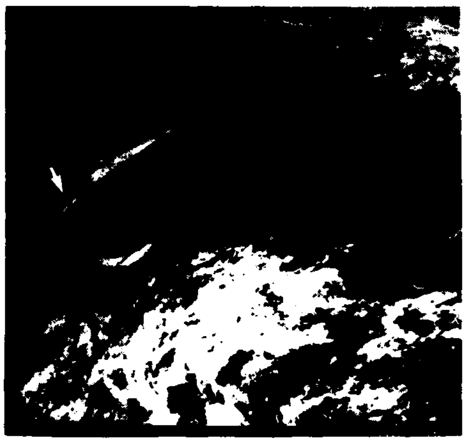


Figure 80: 1547Z 5 December 1979

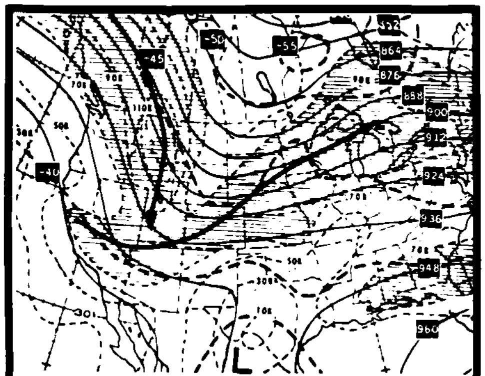


Figure 81: 300MB 1200Z 5 December 1979

Other Jet Stream Identifiers:

Some other cloud characteristics which help in the identification and location of jet streams are cirrus streaks, transverse bands, the size and organization of cirrus anvils, and shadows. Cirrus streaks and transverse bands were introduced in Section 3, Part 1 (see Figures 57 through 59).

• Transverse Bands - Transverse bands are an excellent indicator of the jet speed maximum (and turbulence) within the jet axis. Transverse bands do not appear that often in satellite photos, but when they do, forecasters should be aware of their presence. Transverse banding within a southwest-northeast aligned jet stream system should be watched closely for possible cyclogenesis (near the jet maximum).

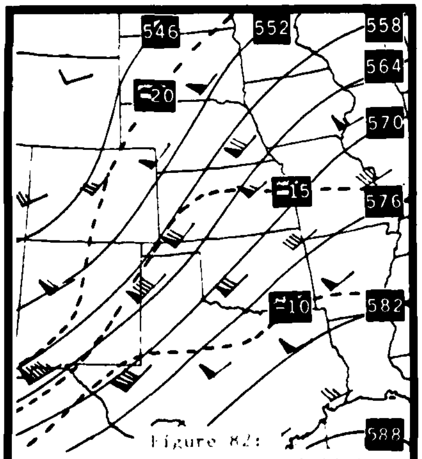


Figure 82: 500MB 1200Z 3 April 1981

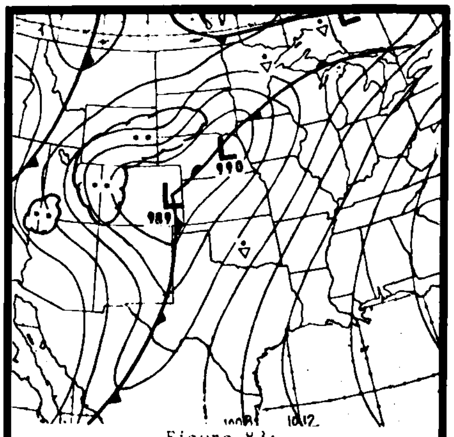


Figure 83: Surface 1200Z 3 April 1981

Figures 82 to 90 depict an example of transverse banding related to cyclogenesis and thunderstorm development. Figures 82 and 83 respectively show the 500mb (300mb data not available) and surface analyses prior to development of this event. In Figure 82, a strong mid-level jet stream is evident across the Great Plains; 90 to [illegible] knots are shown over the Texas panhandle and eastern New Mexico. At the surface, Figure 83, a disorganized storm system is shown.

The first visible satellite picture of this series of photos, Figure 84, shows a zone of baroclinic cirrus across the central Great Plains and is noted by A. Transverse bands can be identified from central Kansas extending southwestward into the Texas panhandle. The polar jet (not shown) would be placed to the left of the baroclinic cirrus area (in the clear area) as exemplified in the model shown earlier in Figure [illegible]. Area B, an area of conditionally unstable air reflected by developing cumulus, lies nearly under the jet maximum and to the northwest of the transverse banding. A stationary mP frontal system is shown across the northern plains.

One hour later, Figure 85, the transverse band's northern portion has moved northeastward into eastern Nebraska as noted by the arrows. Area B begins to develop rapidly and an anvil plume is noted within the cumulus cluster. Speed divergence aloft is primarily responsible for the explosive development shown at area B.

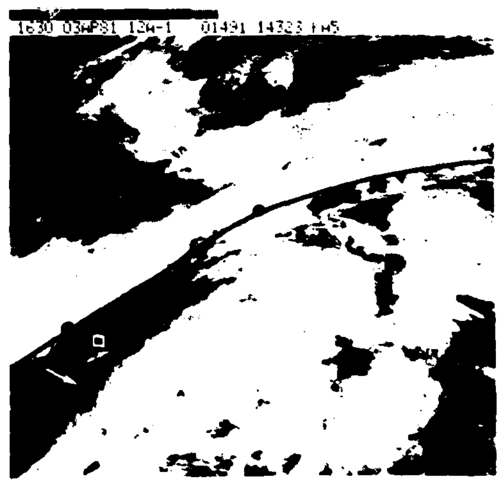


Figure 84: 1630Z 3 April 1981

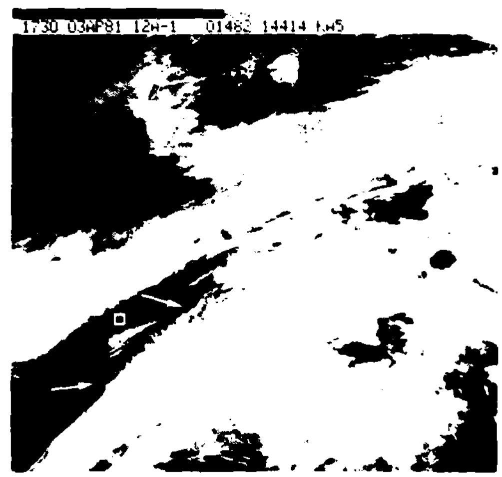


Figure 85: 1730Z 3 April 1981

Let's briefly review the association of transverse banding with thunderstorm development. Since transverse bands are associated with wind maxima, the area upwind from that maxima will undergo speed divergence as indicated in Figure 86. When the area of transverse band moves, the area of speed divergence moves with it. When this area passes over an area of instability, explosive convection can result (Figures 84 and 85, point B). During the winter, this same sequence can explosively develop a weak low level cyclone and result in heavy snowfall.

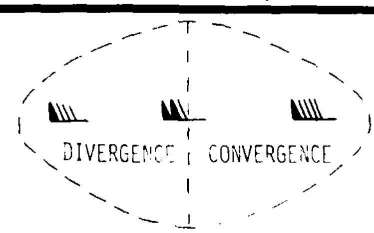


Figure 86:
Example - Speed Divergence/Convergence

About the only way to isolate this area of divergence and track its movement, is with GOES data. After identifying the jet max and determining the speed and direction of movement, forecast a trajectory, and determine if and when the divergent area will pass over any existing low-level disturbances.

Now, let's return to the satellite series. In Figure 87, one hour later, the transverse band area, noted by the arrows, is difficult to see because it has moved into the cirrus shield; it is still moving northeastward and is faintly visible in central Iowa. Area B continues to develop.

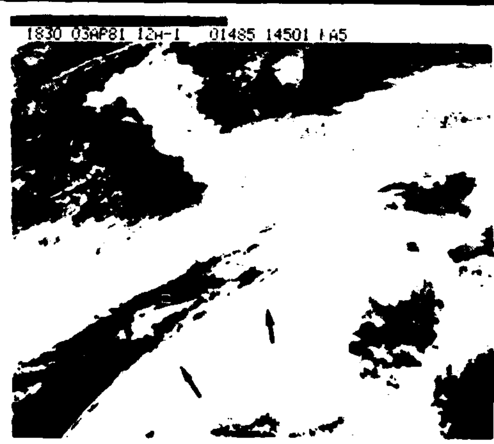


Figure 87: 1830Z 3 April 1981

Transverse banding is now more noticeable in Figure 88 [illegible] later [illegible] as the cirrus shield thins a little. The jet max has now moved into Iowa, area has expanded considerably, and appears to have taken on a comma-shaped appearance. Under [illegible] vorticity analyses were not available for this event; perhaps a small-scale vorticity center existed.

Finally, in Figure 89, transverse banding is still visible over eastern Iowa. The new convection area [illegible] its [illegible] anvil plumes has spread northeastward [illegible] Minnesota. Cyclonic rotation within the striated cloud system over the upper Midwest, is just becoming noticeable.

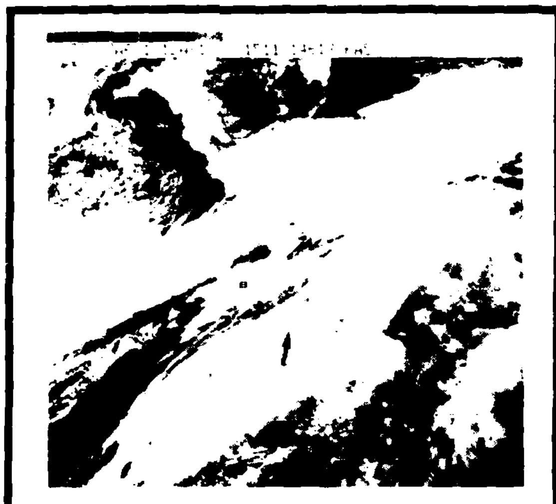


Figure 88: 2030Z 3 April 1981

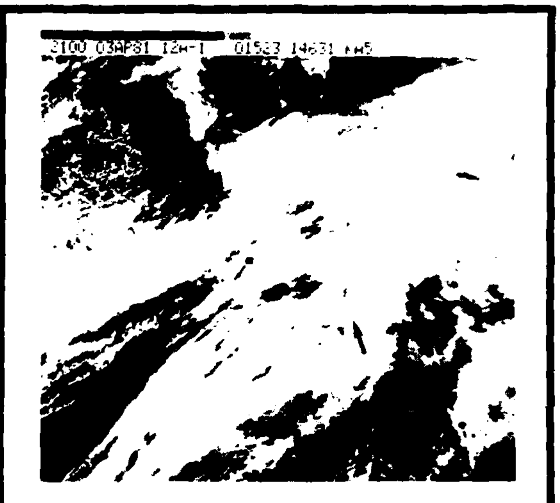


Figure 89: 2100Z 3 April 1981

Figure 90 depicts the surface pattern at 1200Z the following day. An organized storm system, centered in Wisconsin, has evolved. The system's track and its previous 6 and 12 hour centers are respectively shown by the arrows and Xs. The storm moved across eastern Nebraska and Iowa and deepened; undoubtedly triggered by the wind maximum discussed in Figures 84 through 89.

• Anvil Tops - The absence of jet stream cirrus on morning photos may change quickly when afternoon convection, which forms east of the jet stream, develops a series of spreading anvil tops. In Figure 91, young anvil plumes are organizing along a frontal boundary (and east of the upper level jet) of an upper Midwest cyclone. The baroclinic zone, east of the developing thunderstorm line, is cirrus-free; normally this would be the area covered with baroclinic zone cirrus. Perhaps the anvil plumes may quickly spread and fill in the void.

• Shadows - Shadows help define jet stream axes as shown over the eastern U.S. in Figure 92 and across the Gulf of Mexico in Figure 93.

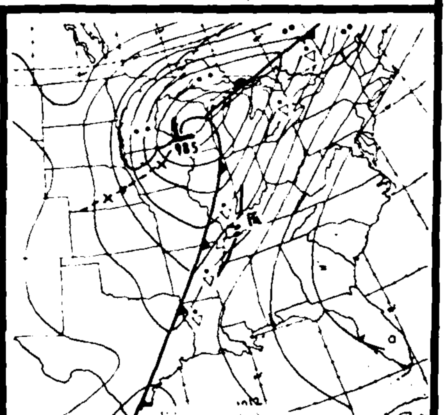


Figure 90:
Surface 1200Z 4 April 1981

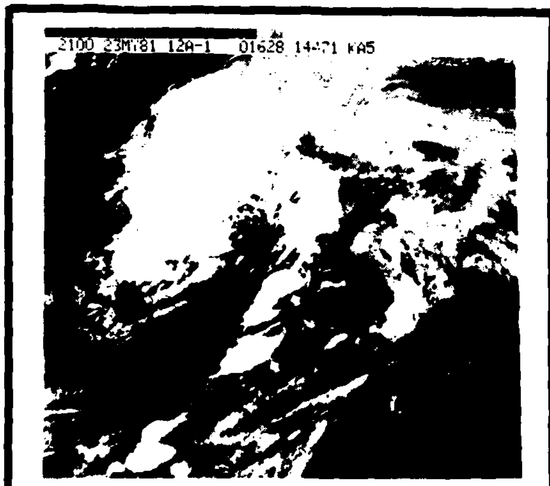


Figure 91: 2100Z 23 May 1981

Figure 92: 1430Z 24 November 1980

Jet Stream Systems:

Figure 93: 1500Z 25 December 1980

• Polar Jet - The driving force within the westerlies in the development of cyclogenesis is the polar jet stream. During autumn the polar jet shifts southward, and by mid-winter, lies across the southern U.S. as shown in Figure 93. As mentioned earlier in this section, several polar jet stream systems or branches may appear simultaneously on upper analyses (see Figure 94). The southern jet [illegible] generally has more extensive [illegible] cirrus and cirrostratus and higher tops than the northern jet stream system.

Figure 95 depicts another common event where several polar jet streams appear on analyses. With a deepening upper trough (increasing amplitude) initial cyclogenesis and extensive baroclinic zone cloudiness are associated with the southern jet. The northern jet becomes aligned north-south within the colder northwesterly flow on the trough's backside and advects in the necessary cold air, and perhaps secondary short waves, to enhance cyclogenesis as shown in Figure 97.

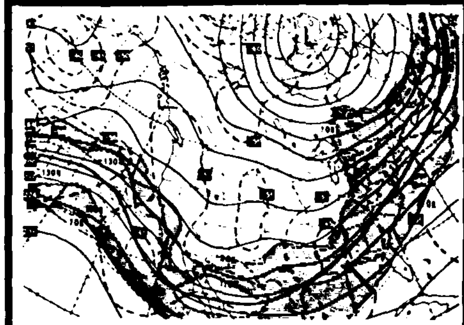


Figure 94: 200MB 1200Z 17 January 1978

NOTE: These jet stream systems may split into smaller branches especially with split flow short wave systems.

• Subtropical Jet - The subtropical jet is the dominant jet stream system across the southern and central U.S. during summer. During the cold season it migrates southward into Mexico as the polar jet becomes the prevailing jet stream system. During winter the subtropical jet may briefly drift northward across the southern plains and Gulf coastal states ahead of low latitude short wave systems moving across Arizona and New Mexico (see Figures 96 and 97).

During the transitional period of spring, the location of the subtropical jet becomes important in severe weather forecasting. The subtropical jet axis delineates the fartherest southern extent of organized severe thunderstorms (large hail and thunderstorms) in a given severe weather outbreak (2).

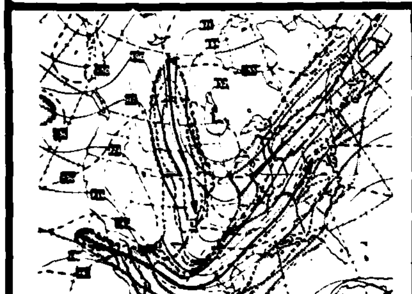


Figure 95:
300MB 1200Z 25 January 1978

• Jet Stream Identification - An Example

Figure 96 illustrates the jet stream pattern ahead of an itensifying short wave off lower California (not shown). The polar jet's southern branch is shown at A; the northern branch is noted at B. A split in the northern branch is identified at C. (NOTE: smaller splits within branches of the polar jet are important to severe weather forecasting. See discussion in Section 8, Part II). The jet stream shown over Florida is the tail end of a short wave offshore. The subtropical jet (D) is not as noticeable because of its close proximity to the southern branch polar jet. On Day 2, Figure 97, the southern branch (A) has shifted northward and merged with the split jet of the northern branch (C in Figure 96). The subtropical jet is now noticeable over southern Texas (D).

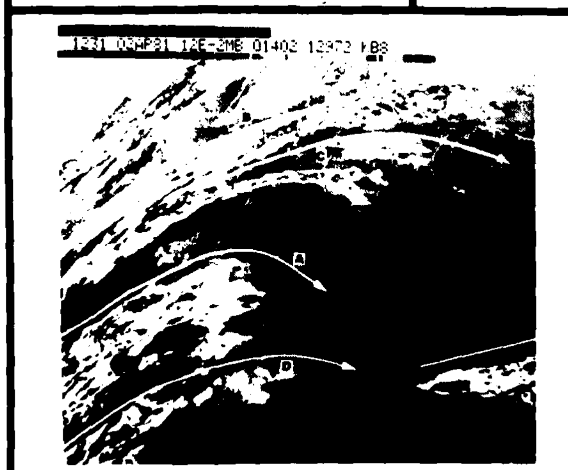


Figure 96: 1231Z 2 April 1981

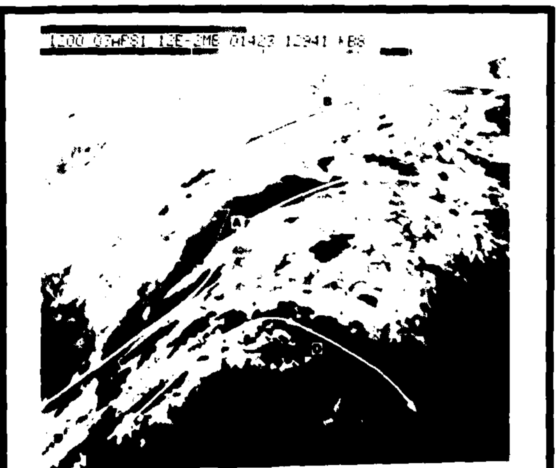


Figure 97: 1200Z 3 April 1981

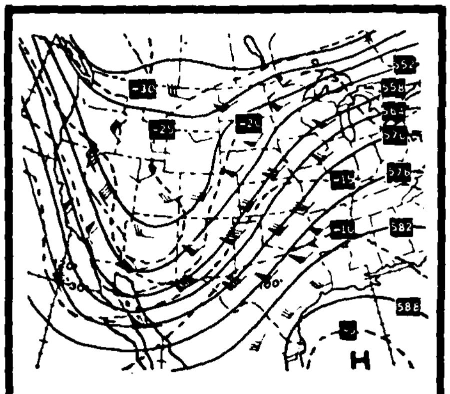


Figure 98: 500MB 1200Z 5 April 1981

Figure 98 depicts the related 500mb analysis; a subtropical anticyclone appears in the Gulf of Mexico.

Non-Jet Stream Cloud Systems:

There are many cloud patterns which look as though they are associated with jet streams but actually have no association with each other. Some of these cloud patterns include deformation zone cirrus. Deformation zone cirrus shields usually form on the northern and west side of an occluded comma system (Figure 99). Deformation zone cirrus is associated with light winds within an upper air col; this col area is shown within the area marked by the location D in Figure 99.

Figure 100, an IR, illustrates a band of deformation zone cirrus (F) across eastern Iowa and northern Missouri associated with an upper Midwest storm system. The cloud system at G is related to the upper tropospheric baroclinic zone and associated jet stream (PVA area). Note in the figure how the two higher level cloud systems narrow over southern Wisconsin (indicated by the arrow); this is the col area of the storm system.

Further discussion of deformation zone cirrus will be presented in Section 7, Part II.

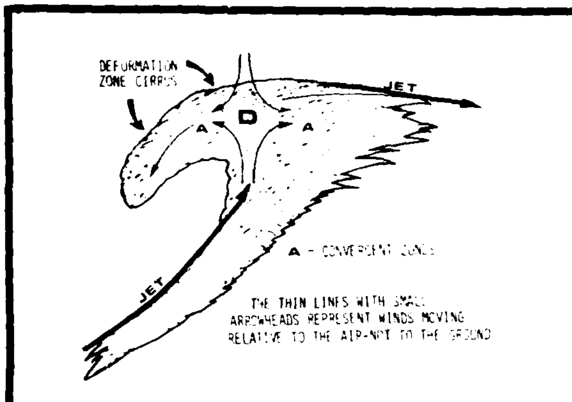


Figure 99: Deformation Zone

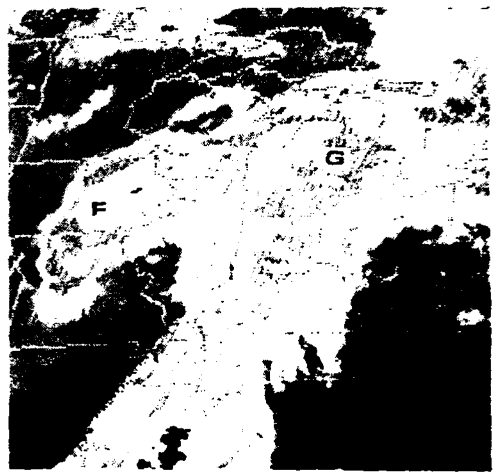


Figure 100: 1130Z 14 May 1981

Figure 101: 1130Z 25 December 1981

Miscellaneous:

- During winter, when a major trough pattern prevails, the southern polar jet stream will push deep into the southern latitudes. The subtropical jet and the polar jet will appear to have merged and become one long, continuous jet stream system; this is shown in Figure 101 by an extensive cirrus band from Nova Scotia to the Pacific area.

The segment from Texas extending northeastward (A) is the polar jet (at a lower level); the subtropical jet (higher level) is noted from Texas extending southwestward (B). The subtropical jet segment can be identified by higher cloud tops (in the IR) and anticyclonic curvature. The lower polar jet leaf reveals lower tops and cyclonic curvature. The two jet streams will eventually split; the subtropical jet cirrus band will persist while the polar jet stream cirrus will move away, dissipate or move northward ahead of the next approaching disturbance. In Figure 101, the northern polar jet stream is shown over the western and central U.S.

- Jet stream locations within comma cloud and baroclinic leaf systems and various cyclogenetic models will be shown in subsequent sections of this Technical Note.

- Advective and channeled jet streams are often mentioned in satellite interpretation messages; definitions of these jet systems will be presented in Section 3, Part II.

Ridges:

Upper ridges in mid-latitudes can best be located by [illegible]. The width of the cloud pattern, its orientation and the character [illegible] edge can be used to determine the amplitude or sharpness of the ri[illegible] can be categorized into three main groups consisting of sharp, [illegible].

• Sharp Ridges - A sharp ridge has a narrow cloud band, a north to south orientation and the cloud system has a sharp leading edge (little, if any, spillover of clouds over the ridgeline; Figure 1[illegible]). Sharp ridges will be relatively narrow due to the close spacing of the trough and ridge which results in a narrow area of upward vertical motion. Consequently, the leading edge of the cloud band will end abruptly at the ridgeline due to the rapid change from upward to downward motion. A sharp ridgeline pattern is shown in Figure 1[illegible]; the related IR photo, Figure 104, shows the forward edge of the cloud system ending at the ridgeline.

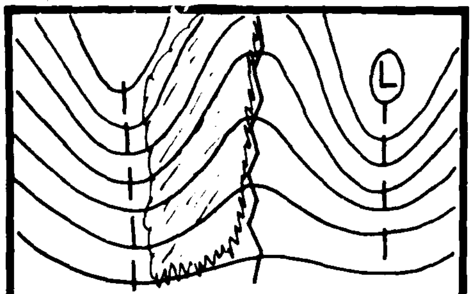


Figure 102: Sharp Ridgeline Pattern

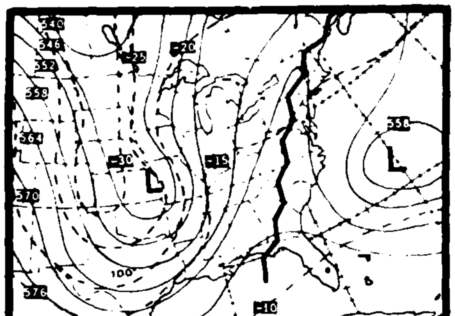


Figure 103:
500MB 1200Z 22 February 1981

Figure 104: 1130Z 22 February 1981

Another sharp ridgeline pattern is shown in Figure 105; this pattern is associated with blocking systems. This pattern occurs more often over the eastern Pacific during the winter months when a major ridge builds and persists along or off the west coast of North America and northward into Alaska. Figures 106 and 107 illustrate this event. Trough systems approaching from the west decelerate as they approach the blocking ridgeline. The cloud system becomes stationary and may linger for several days or longer until the blocking ridge flattens or shifts to another area. In these patterns, short waves either move northward west of the ridge towards Alaska or move southeastward towards California (eventually eroding the southern portion of the blocking ridge.) Sharp ridgelines are generally associated with slow-moving meridional trough/ridge systems.

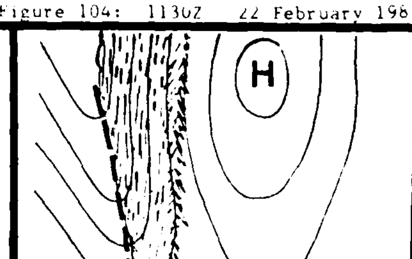


Figure 105:
Sharp Ridgeline - Blocking Pattern

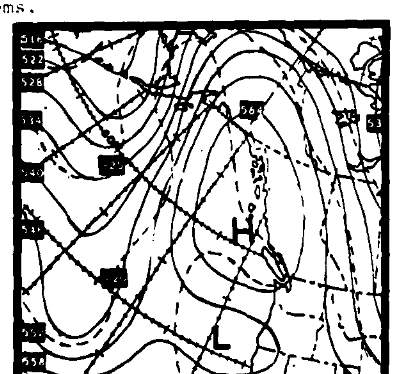
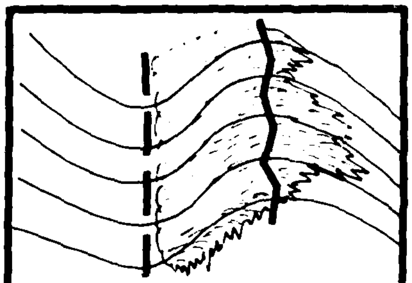
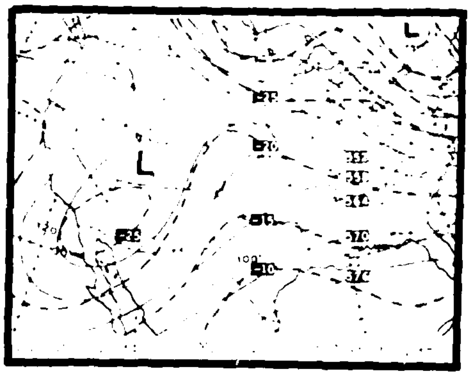


Figure 106:
500MB 1200Z 11 February 1980

Figure 107: 1215Z 11 February 1980





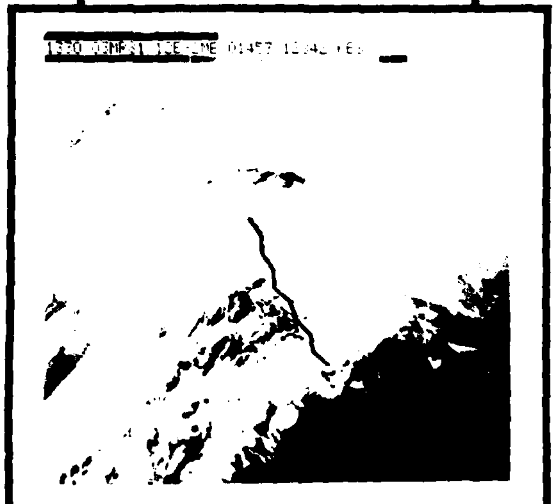


Figure 111: [illegible]Z 3 March 1981

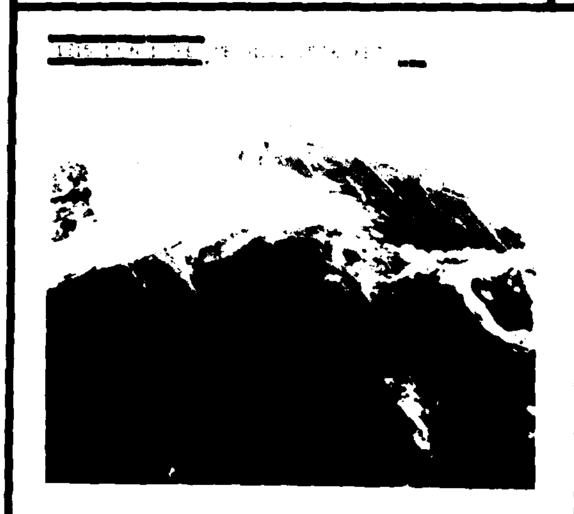
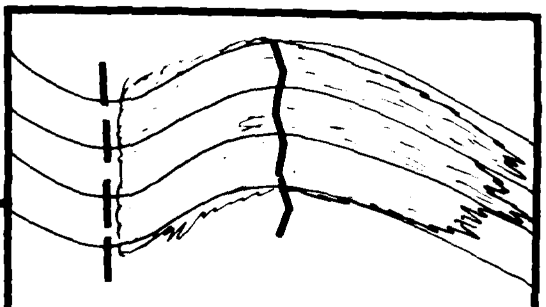
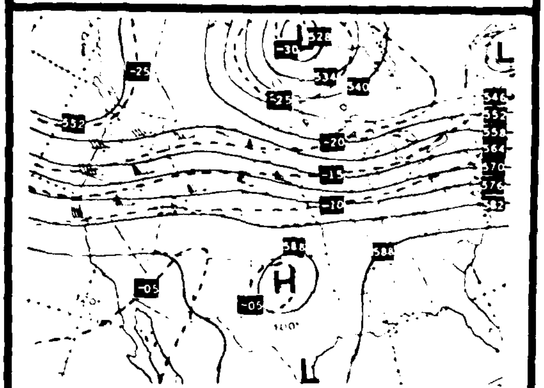


Figure 112: 1315Z 10 June 1981





[illegible] the most beneficial information that [illegible] following cloud systems [illegible] is determining changes in the sharpness [illegible] upper [illegible]. In Figure 11[illegible], a model of a low amplitude [illegible] shown with clouds spilling [illegible] the ridge line. Figure 11[illegible] illustrates a model [illegible] ridge (sharp), strong [illegible]. Forecasters can follow continuity of the ridge [illegible] to determine if a low is intensifying or if it is beginning to break down a [illegible] ridge pattern. If continuity [illegible] cloud sequence [illegible] Figure 11[illegible], [illegible] Figure 11[illegible], the [illegible] and the ridge [illegible]. The opposite would be true if the trend was reversed.

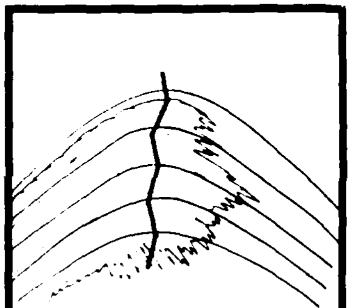


Figure 11[illegible]: [illegible] Amplitude Ridge - [illegible]

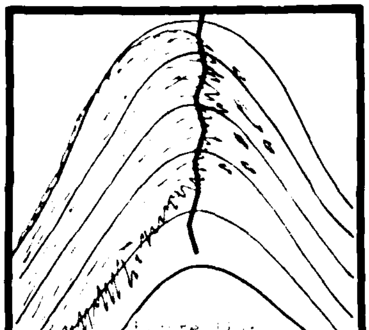


Figure 11[illegible]: High Amplitude Ridge - Later

Troughs:

The change in the sign of the vertical motion and wind directions at the troughline is reflected on satellite pictures by differing cloud patterns. Three of the most common cloud patterns used to identify the location of mid and upper troughs are: breaks in frontal bands, enhanced cumulus clouds and comma-shaped clouds. These three patterns and combinations thereof should aid forecasters in locating most trough systems.

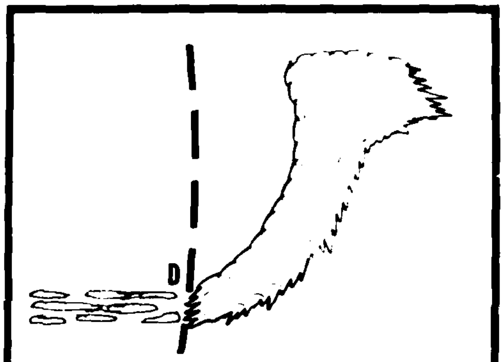


Figure 119: Troughline Identification

• Frontal Cloud Bands - The mid tropospheric troughline can frequently be located where a frontal band and trough intersect as shown at point D in Figure 119. At this point of intersection, the frontal clouds will lessen, become *fragmented or disappear where the mid level* vertical motion changes from upward to downward at the troughline. Figures 117 and 118 illustrate cloud pattern changes (points D) where troughlines intersect frontal bands. East of the troughlines and *along the active bands*, cloud tops reach into the mid and upper levels reflecting upper vertical motion (and precipitation). West of these troughlines, frontal bands become inactive, change cloud character and decrease in coverage; the clouds are primarily low clouds reflecting mid and upper level downward vertical motion (little, if any, precipitation).

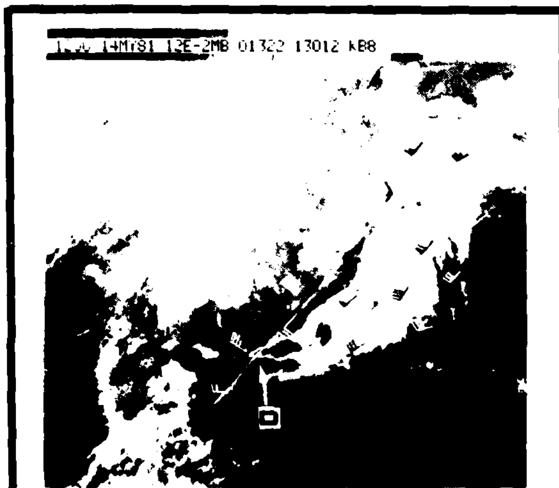


Figure 117: 1200Z 14 May 1981

Figure 118: 1845Z 21 October 1980

• Enhanced Cumulus - Areas of positive vorticity advection are reflected in the appearance of cellular clouds to the rear of cold fronts. The upward motion produces areas of enhanced cumulus. These areas are observed frequently over oceanic areas (and less over land) where there is an abundance of lower level moisture. In Figure 119, an area of enhanced cumulus is noted by the arrow along and to the east of the troughline. The 500mb analysis, Figure 120, (five hours earlier from Figure 119) shows the troughline west of California.

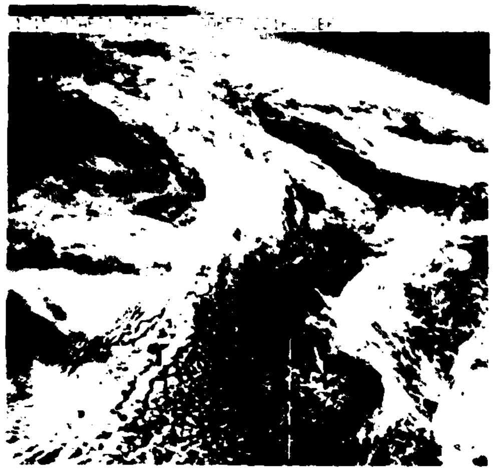


Figure 119: 1715Z 2 April 1981

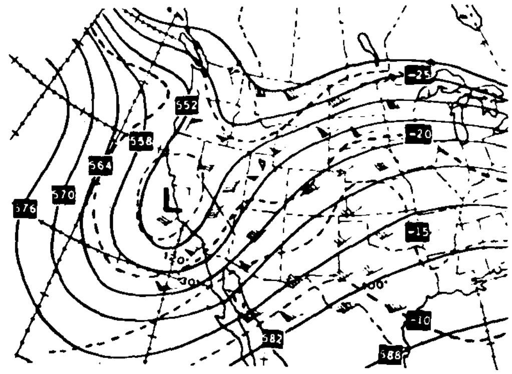


Figure 120: 500MB 1200Z 2 April 1981

Continued vertical development of enhanced cumulus areas (associated with PVA) eventually will form small comma-shaped cloud systems. The anvil plumes reach into the mid and upper levels and form comma-shape cloud systems. This is more likely to occur over land areas during the warm season; Figures 121 through 123 depict such an event over land. In Figure 121, an area of enhanced cumulus appears over most of Mississippi and is noted as area G. The troughline associated with this short wave system is also shown and is placed to the left of the enhanced cumulus area. Further to the east over Alabama, a comma-shaped cloud system (area H) has developed from enhanced cumulus. The related IR photo, Figure 122, shows the vorticity comma cloud system very well (see arrow). The related 500mb analysis (Figure 123; seven hours earlier) shows the short wave trough system.

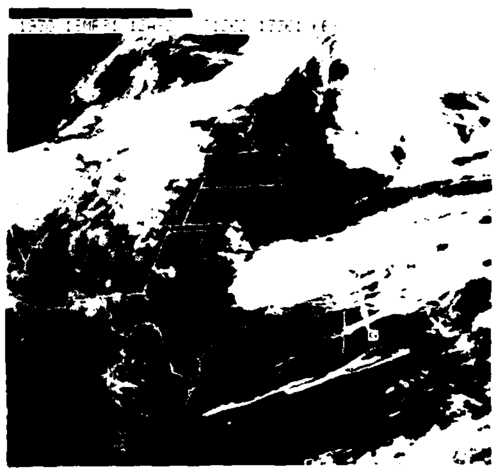


Figure 121: 1930Z 18 March 1981

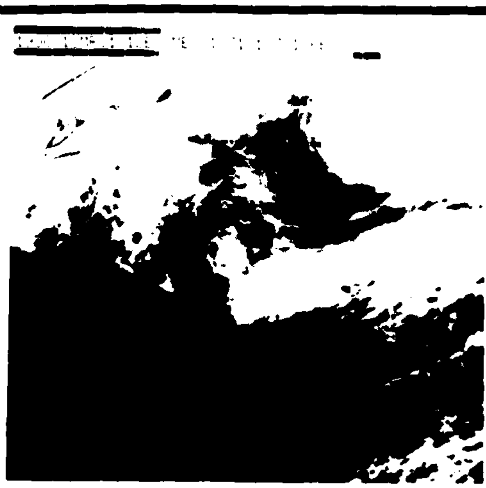


Figure 122: 1900Z 18 March 1981

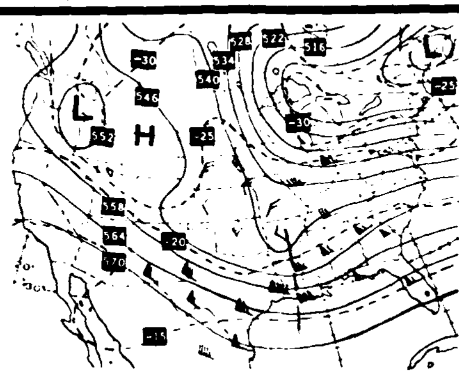


Figure 123: 500MB 1200Z 18 March 1981

Enhanced cumulus areas located well to the rear of a short wave comma cloud system often reflects either the major trough's position or the presence of a new vorticity center within the cold air of the trough system. An example is shown in Figures 124 and 125. In Figure 124, a short wave comma cloud system is shown over the eastern U.S. The [illegible] band stretches southwestward across southern Georgia and into the Gulf of Mexico. The band becomes fragmented at point F reflecting a change from upward to downward vertical motion in the middle to high levels. The short wave's troughline can be placed at point [illegible]; however, when looking at the 500mb analysis shown in *Figure 125*, forecasters would be hard pressed to locate the troughline. The main troughline and cold air is located further to the west across the central and southern plains as revealed in Figure 125. In Figure 124, the enhanced cumulus area noted at location G over the central Great Plains has developed within the cold air pocket of the major troughline. Forecasters should be alerted, especially during spring (winter), for possible cold air thunderstorms (snow showers) developing in these enhanced cumulus areas.

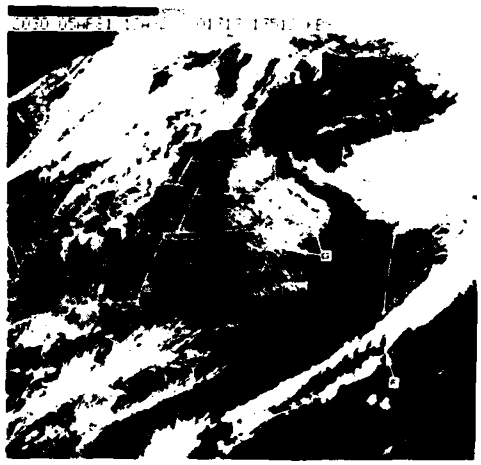


Figure 124: 2030Z 5 April 1981

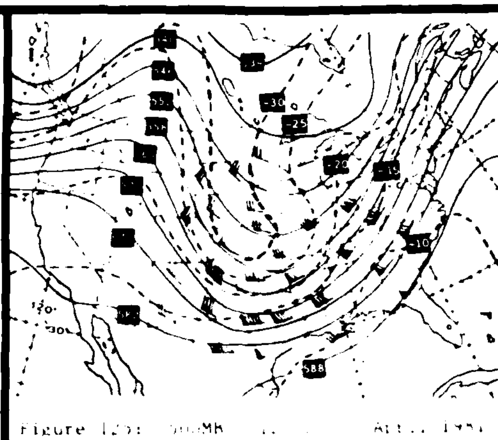


Figure 125: 500MB [illegible] 1981

• Other Comma-Shaped Cloud Systems - In the preceding discussion it was shown that vorticity comma cloud systems often develop within enhanced cumulus areas. Mid tropospheric level troughlines can also be located using other vorticity comma shape cloud patterns. Over land areas during the cold season, many vorticity comma cloud patterns to the rear of major cyclones are mid-level features and appear to be strati-form in satellite pictures. *These systems*, however, are often highly convective, but they generally do not produce anvil plumes. Figures 126 and 127 depict two such events.

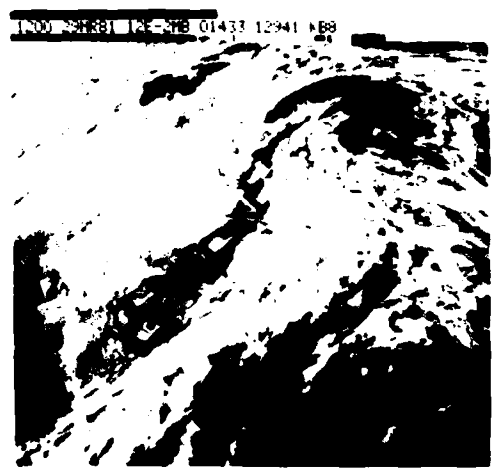


Figure 126: 1200Z 29 March 1981

In Figure 126 (500mb; 1200Z wind data has been added), a vorticity comma cloud system is noted at location B, and it is located to the rear of the larger comma system. The troughline can be placed to the rear of the comma cloud at location B and also to the rear of the small mid-level cloud system over southern New Mexico. The IR *temperature* scale indicates that the vorticity comma is primarily composed of mid-level clouds.

A second example is shown in Figure 127. The vorticity comma head is noted at B; the comma tail extends southeastward across southeastern Missouri. A negative-tilt (oriented northwest-southeast) short wave trough can be placed to the rear of the comma cloud. The related 500mb analysis, Figure 128, shows the minor short wave within the flow of the long wave trough system. Negative-tilted short wave systems such as shown in Figure 127 are often dynamic systems and produce strong cyclones.

The tail end of the short wave troughline in Figure 127 is placed at the bend in the frontal cloud band noted at point E. This bend reflects the area of maximum cyclonic curvature upwind of the inflection point shown at point F. Returning to Figure 128, a jet maximum axis of 90 knots across northeastern Texas into central Arkansas can be seen; this jet maximum is reaching northeastward and is reflected by the bend in the cloud frontal band.

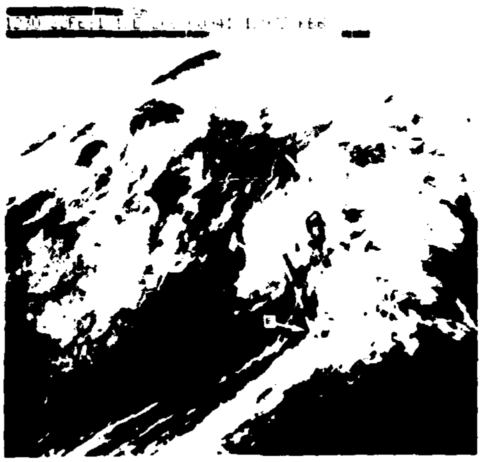


Figure 127: 1230Z 22 February 1981

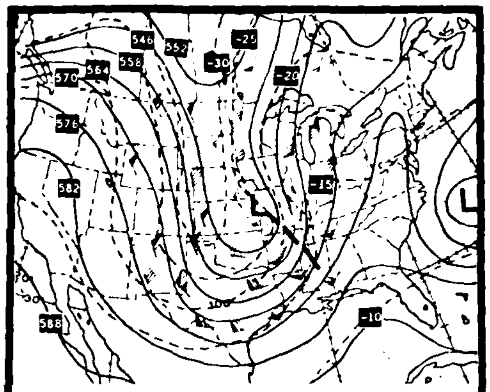


Figure 128: 500MB 1200Z 22 February 1981

• Cirrus Streaks - Forecasters should evaluate all cloud systems for hints in determining troughline positioning. Cirrus streaks may be helpful; this is shown in Figure 129. In Figure 129, a west to east cirrus streak is noted across the Gulf of Mexico. A bend in the streak is shown at point T; this bend reflects maximum cyclonic curvature. Three features in Figure 129 (two have been presented earlier) can identify the general location of the troughline. First, the troughline lies west of the vorticity comma cloud noted at S (hard to see). Secondly, the troughline can be placed in the cyclonic curvature of the cirrus streak. Finally, the cloud frontal band terminates at point U reflecting a change in mid and upper level vertical motion.

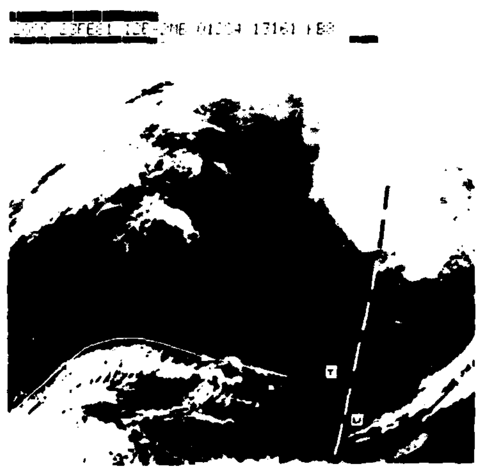


Figure 129: 2000Z 23 February 1981

Northeast-Southwest Aligned Troughs:

The situations described earlier in troughline identification primarily exist with troughs oriented north to south. There are those occasions, however, when troughs become oriented northeast to southwest (positive tilt) as do the cloud patterns accompanying them. In these cases, the upper level trough does not actually intersect the frontal cloud band so the strong change in cloud character is not evident. Figure 130 is an example of such a system. In these cases, clouds to the northwest are suppressed due to downward vertical motion, but convection, overrunning and low-level convergence team up to produce clouds on the right side of the troughline. In Figure 130, the chance for frontal wave development increases in area D where the cloud frontal band lies parallel to the trough axis. Examples of this type of trough orientation are illustrated in Figures 131 through 134.

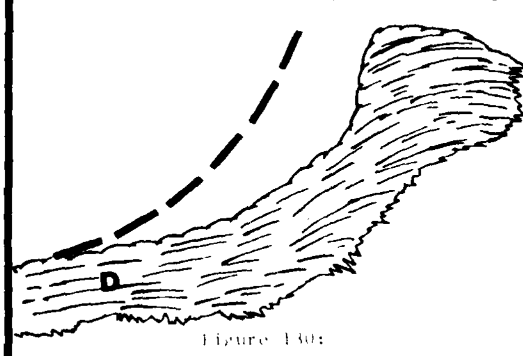


Figure 130:
Northeast-Southwest Aligned Trough Pattern

• Example 1 - In Figure 131, the 500mb analysis shows a short wave system moving across the central and upper Midwest. A closed low appears over Mexico. The short wave trough's southern location across Texas is becoming oriented northeast to southwest. In the related visible satellite photo, Figure 132, a cirroform layer is evident across the southern plains (point C) and is spreading northeastward up the frontal cloud band. The cirrus layer is a result of convection which developed across central Texas ahead of the closed low.

• Example 2 - During the warm season, thunderstorm activity often breaks out (especially at night) along and to the right of upper troughlines oriented northeast to southwest. The 500mb analysis, Figure 133, reveals a trough system oriented northeast to southwest across the southern plains. In Figure 134, widespread cloudiness with some thunderstorm activity is clearly evident across Texas and Mexico.

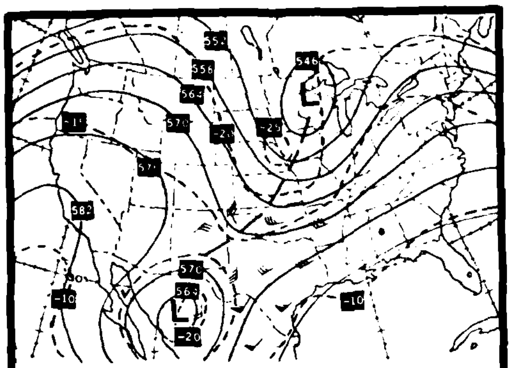


Figure 131: 500MB 1200Z 23 April 1981

Figure 132: 1400Z 23 April 1981

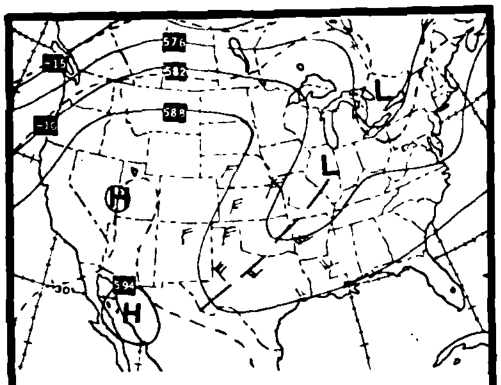


Figure 133: 500MB 1200Z 5 July 1981

Figure 134: 1200Z 5 July 1981

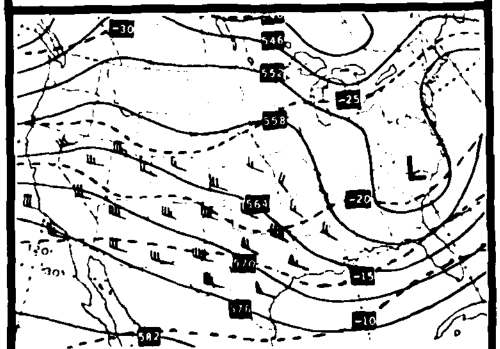


Figure 135:
500MB 1200Z 23 March 1981 (Day 1)

Trough Deepening:

The following example depicts trough deepening within an east to west upper level west of the Rocky Mountains. On Day 1, Figure 135, a west to east 500mb flow prevails over the western U.S. No significant trough system is approaching the West Coast. Some slight thermal troughing is noted over the Rockies.

On Day 2, Figure 136, a trough is evident across Utah and Arizona. The related satellite photo, Figure 137, identifies the trough system very well. During this early stage of development, the troughline can be placed immediately behind the cloud system as indicated in Figure 137. The surface pattern is shown in Figure 138; no surface frontal system appears in the area of the deepening upper trough.

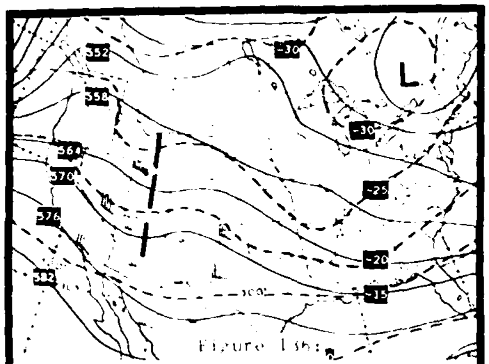


Figure 136: 500MB 1200Z 24 March 1981 (Day 2)

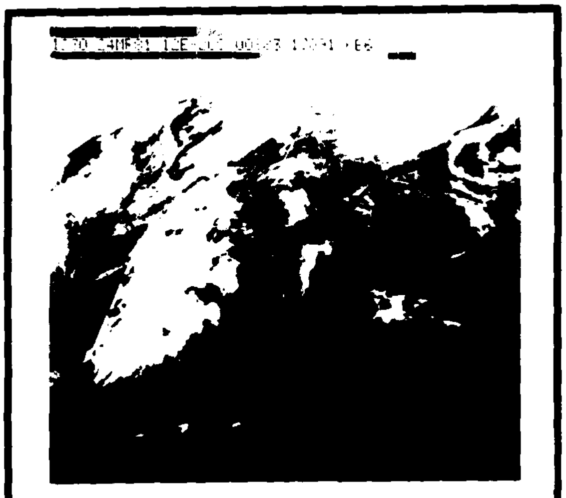


Figure 137: 1230Z 24 March 1981

Figure 138: Surface 1200Z 24 March 1981

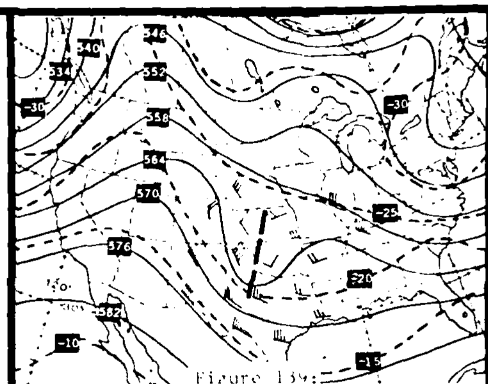


Figure 139: 500MB 1200Z 25 March 1981 (Day 3)

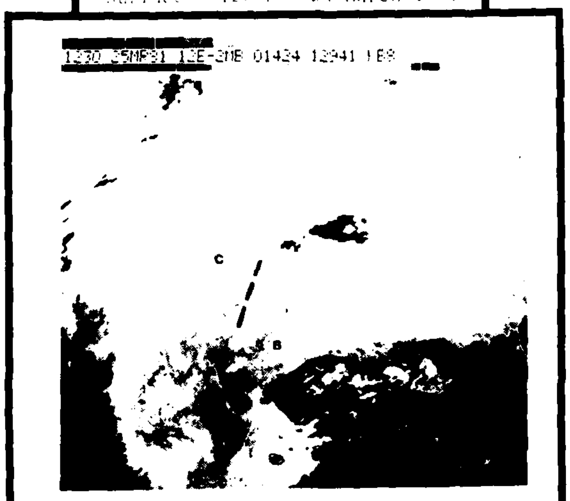


Figure 140: 1230Z 25 March 1981

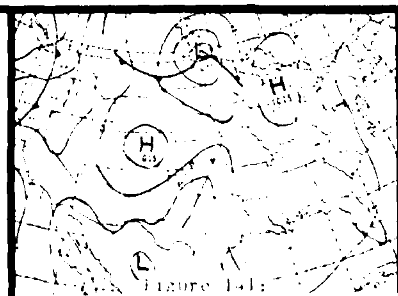


Figure 141: Surface 1200Z 25 March 1981

By Day 3, Figure 139, the trough has continued to deepen and has moved out of the Rocky Mountains. A jet maximum (60 knots) appears at the base of the trough. In the satellite photo, Figure 140, some cyclonic organization is beginning to take shape. The vorticity cloud system is noted at location B, but it has not yet assumed a comma-shape appearance. The troughline lies just west of the vorticity cloud system as shown in Figure 140. A narrow band of deformation zone clouds is noted at location C which may give a hint that a low could subsequently develop within the base of the trough over Oklahoma.

The surface analysis, Figure 141, depicts an inverted trough pattern across the central and southern plains - a reflection of the deepening upper trough. This example typifies those situations when cold fronts suddenly develop east of the Rocky Mountains. In addition, explosive cyclogenesis can occur in the northern portion of the inverted trough below the upper level trough system.

SECTION 3: Significant Mid and Upper Level Cloud Systems

The purpose of this section is to give the reader an overview of certain mid and upper level cloud systems which appear on satellite pictures and are significant to storm development. The next four sections of this part of the Technical Note (TN) and Part III, Patterns of Cyclogenesis, will discuss these cloud systems in detail. Additionally, terminology such as advection and channel jets and vorticity lobes, which are being used in satellite interpretation messages and satellite literature, will be presented. Forecasters should have an understanding of what these terms represent.

Cloud Systems of a Developing Storm:

The three primary cloud systems which comprise a synoptic comma cloud system within the westerlies are as shown in Figures 142 through 144. They are:

- Baroclinic Zone (A; Figure 142)
- Vorticity Comma Cloud (B; Figure 143)
- Deformation Zone (C; Figure 144)

The letter shown in parenthesis behind each cloud system above will be used throughout this TN *to identify these particular cloud systems (after Weldon, 1975).*

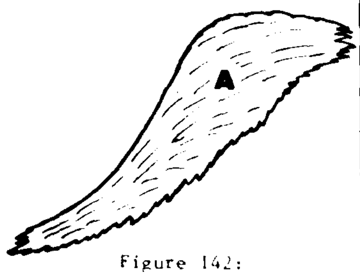


Figure 142:

Baroclinic Zone Cloud System

(Highest level cirrus tops - usually stratiform; precipitation usually steady except for thunderstorms. Cold/occluded and warm fronts are associated with this cloud pattern.)

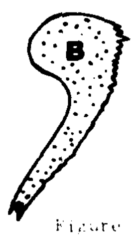


Figure 143:

Vorticity Comma Cloud System

(Mid to low level cloudiness - highly convective; precipitation usually showery. Cold occluded fronts are associated with this cloud pattern.)

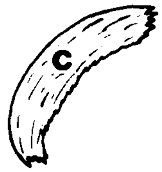


Figure 144:

Deformation Zone Cloud System

(Cirrus level tops but they are lower than baroclinic zone cirrus; precipitation is steady. Occluded fronts are associated with this cloud pattern.)

These three cloud systems have been placed in their respective positions in the model of a mature comma cloud system shown in Figure 145. It will be shown later in Part III that cyclogenesis occurs in different ways, and that the primary consideration for identification of different types of cyclogenesis is the order in which these cloud systems develop. In Figure 145, the primary vorticity comma cloud (B) is often hidden below the higher level cirrus layers and cannot be observed on satellite photos. In the visible photo, Figure 146, however, the higher level baroclinic cloud shield (A) has moved faster than the mid-level vorticity comma cloud (B), consequently, the vorticity comma can be seen. Area C identifies the related deformation zone cloud band.

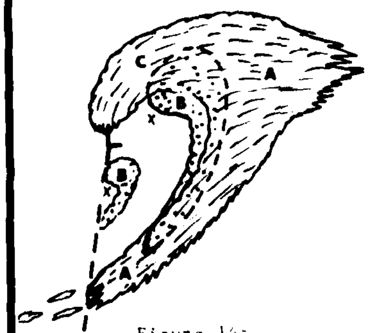


Figure 145

Composite

Mature Comma Cloud System

Figure 146: 1430Z 14 May 1981

Figure 1[illegible] illustrates these three cloud systems within a disorganized storm system over the western Pacific. Area A identifies a large, south to north baroclinic zone cloud system. A well developed vorticity comma cloud (with cirrus plumes from deep convection) is noted in area B. The comma cloud most likely developed from the enhanced cumulus area located south of area B. Area C indicates a band of deformation zone cloudiness.

Figure 1[illegible]: [illegible] 2[illegible] February 19[illegible]

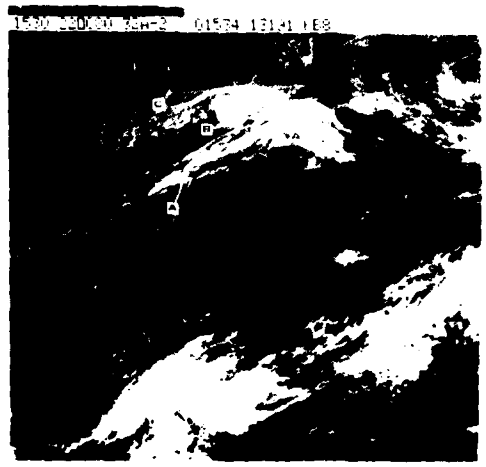


Figure 1[illegible]: [illegible] October [illegible]

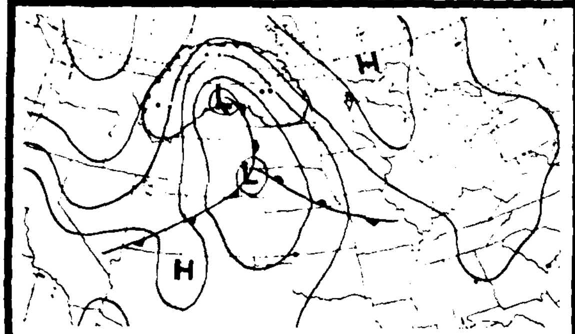


Figure 149: Surface [illegible] October [illegible]

A third example is shown in Figure 148 across the northern Rockies and Northern Great Plains. In the visible photo, the baroclinic cloud shield and band (A) is well defined from the Colorado Rockies to Minnesota. Part of the vorticity comma cloud (lower cloud layer and convective) is noted at B; the rest of the comma cloud is hidden under the baroclinic zone cirrus layer. Deformation zone clouds can be seen in area C. The related surface analysis, Figure 149, shows the storm system over the northern Rockies. (Note: the jet stream can be located to the left of the baroclinic cloud system; also, note jet stream formation along and east of the Colorado Rockies; see Figure 80.)

Baroclinic Leafs:

It has been observed in satellite photography that many comma cloud systems evolve from deep cloud systems which often resemble a leaf pattern. They usually form on the east side of high amplitude trough systems. In Figure 150, a leaf-type cloud system is shown during the initial stage. Later, Figure 151, the leaf has evolved into a comma cloud system. These leaf systems will be presented in the next section.

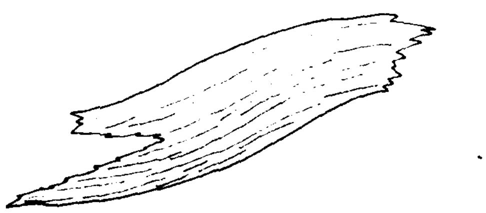


Figure 150: Baroclinic Leaf - Initial

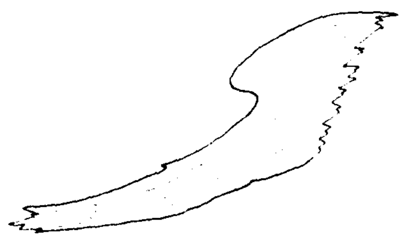
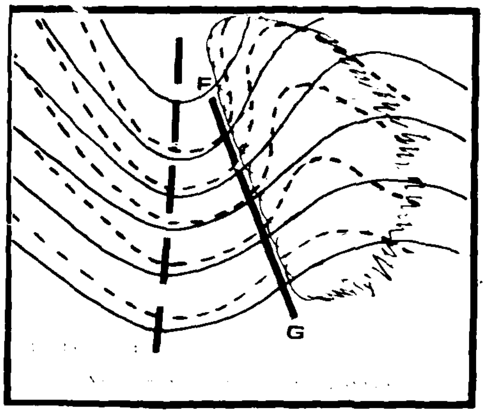
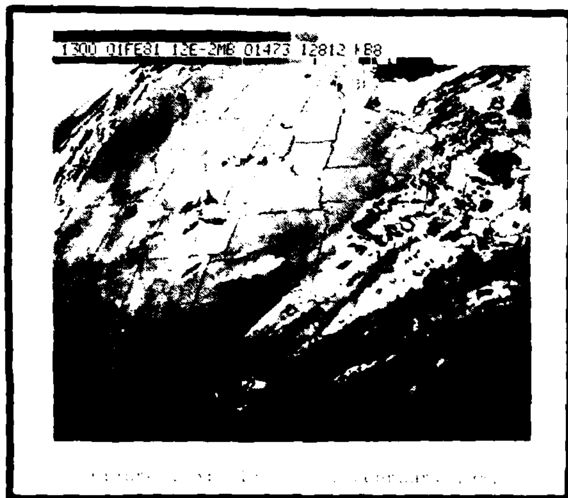


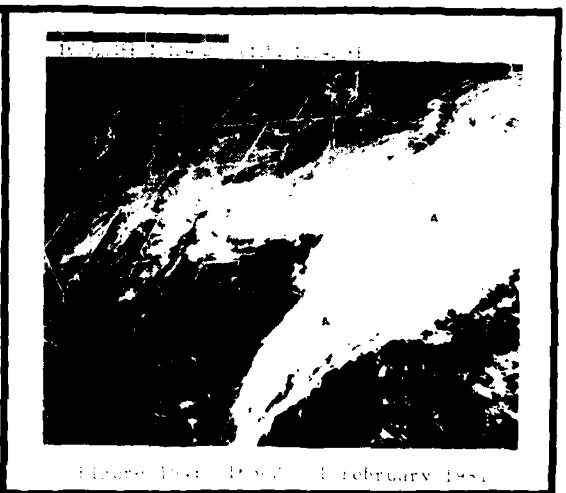
Figure 151: Young Comma Cloud

[illegible] likely the [illegible]. In Figure [illegible], the highest cloud tops [illegible] this is the area where the thermal [illegible] (VA) shown in Figure [illegible] is most [illegible].

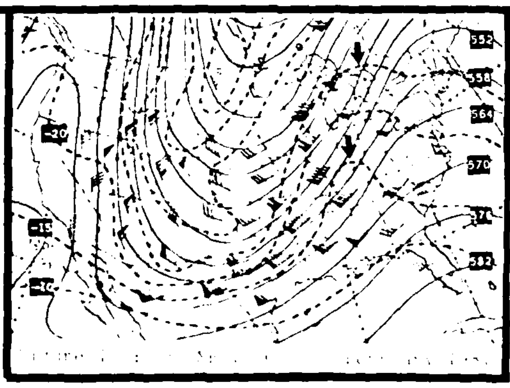




[illegible]



[illegible] 1 February 1981



[illegible]

[illegible]

The deepest baroclinic zone cloud systems are associated with large, high amplitude trough systems located within the mid-latitude westerlies. These deep cloud systems are observed more often east of the Rocky Mountains where there is an abundance of moisture from the Gulf of Mexico and the Atlantic Ocean. Conversely, baroclinic zones may have little, if any, cloudiness associated with them. This is likely to occur over the western Great Plains and westward. The first visible signs of the baroclinic zone are cirrus layers appearing east of the trough line. The cloud system increases as it moves eastward into a more favorable area for lower level moisture across the central Midwest and eastward.

Forecasters may say that these cloud systems are simply cloud frontal bands. In most cases, yes, they are. However, not all jet stream related mid and high level baroclinic zones have lower level related frontal systems.

Relationships between 500MB Height Contours and Vorticity Isopleths:

The following information describes terminology which may appear in satellite interpretation messages and forecast bulletins.

Jet Stream:

In Section I, Part II, jet streams were shown as continuous belts of strong upper level winds extending across large areas. Another approach is to consider these strong middle and upper level wind zones as separate, but interrelated, jet stream segments or *speed maxima*. This approach is more useful for understanding and interpreting cloud systems observed on satellite pictures. Note: In the following 500mb illustrations, the solid lines are height contours; dashed lines are vorticity isopleths.

• Channel Jet - A "channel jet" is a jet stream segment in which height contours and vorticity isopleths intersect at small angles or are parallel. (A channel jet is usually associated with a shear lobe; to be shown later.) In Figure 157, the heavy arrowheads mark a channel jet pattern: the vorticity maximum (not a PVA maximum) shown in Figure 157 over Michigan has a channeled zone around its southwestern quadrant. Other characteristics of channel type pattern are:

· Within well defined channeled zones, the 500mb isotherms are parallel to the wind direction, height contours and the axis of maximum winds. Additionally, during the winter season, well defined channeled regions have large vertical depth.

· The strongest winds aloft are usually found in the channeled regions.

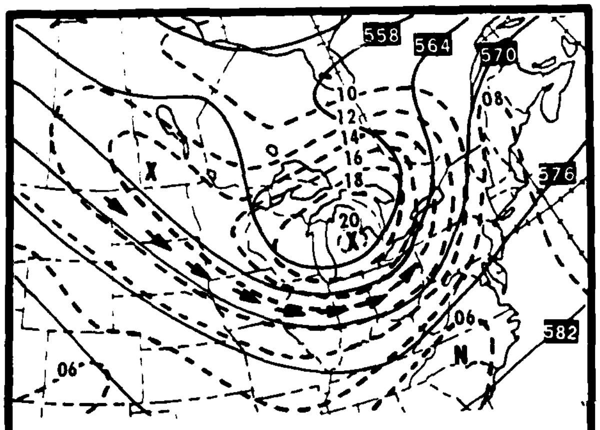


Figure 157: 500MB Height/Vorticity Analysis Chaneled Jet Stream

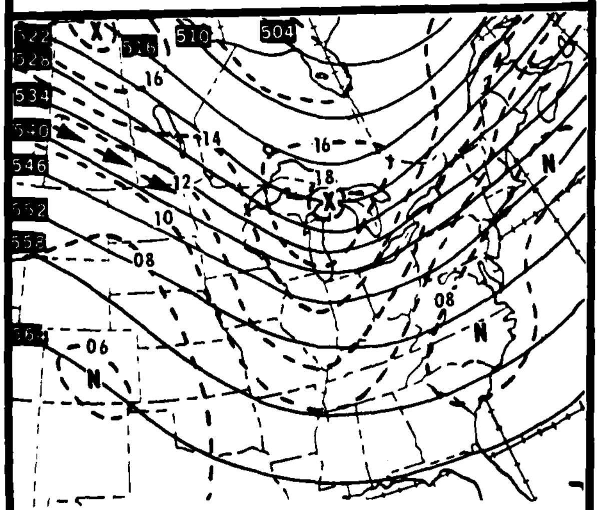


Figure 158: 500MB Height/Vorticity Analysis Advection Jet

• Advection Jet - An "advection jet" is a jet stream segment in which the height contours intersect vorticity isopleths at large angles in the area of maximum winds (an advection jet is usually associated with advection lobes). In Figure 158, the strong wind zones within the large vorticity field are mostly of the advection type, except as noted in the channeled region by the arrowheads. Other characteristics of the advection type pattern are:

· The axis of maximum winds is <u>not parallel</u> to the wind direction or the contours; this is shown in Figure 159. In Figure 159, the 500mb maximum winds of $\geq$ 100 knots (shaded area) cross the contour flow along a south to north axis. The wind direction, however, follows the contour flow. (This pattern indicates strong PVA; the temperature and moisture fields would also cross the contours at large angles as discussed earlier in Figure 152.)

· Over PVA areas, the axis of maximum winds aloft shifts to lower height contours (looking downstream). Over NVA areas, the axis of maximum winds shifts to higher contours (looking downstream).

· The jet stream axis of maximum winds is not as well defined over regions of advection jet structure, as it is over channeled regions.

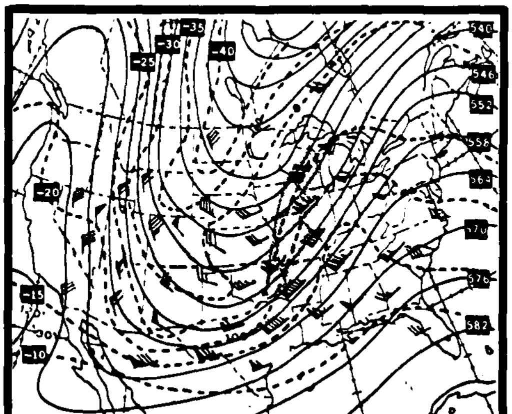


Figure 159: 500MB 1 February 1980

Vorticity lobes:

A vorticity lobe is an elongated ridge or trough in the [illegible] associated with vorticity maxima or vorticity [illegible]. [illegible] vorticity lobe to separate areas of positive vorticity [illegible] vorticity advection. This is especially true [illegible] wind of the vorticity lobe. This can further be [illegible]. If clouds exist where PVA is indicated, then the [illegible].

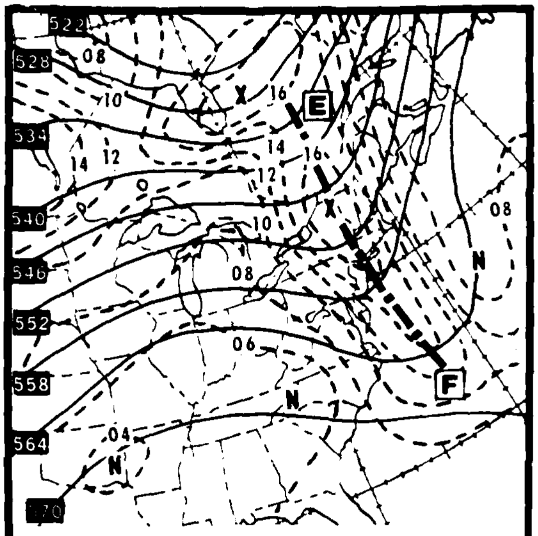


Figure 160: 500MB Height Vorticity Analysis Advection Lobes

Figure 161: [illegible]

• Advection Lobe - An advection lobe is a vorticity lobe whose axis crosses the height contours at large angles (related to advection jets). In Figure 160, the lobe's axis noted between E and F reveal a negative tilt pattern - east of axis E-F strong PVA, considerable cloudiness and precipitation and the likelihood of frontal cyclogenesis would occur. An example is shown in Figures 161 and 162. In the satellite photo, Figure 161, two lobes of vorticity with PVA and clouds are noted at locations [illegible] and E east of the lobe axes. These correspond closely to the related 500mb vorticity pattern shown in Figure 162 ([illegible] hours later from Figure 161).

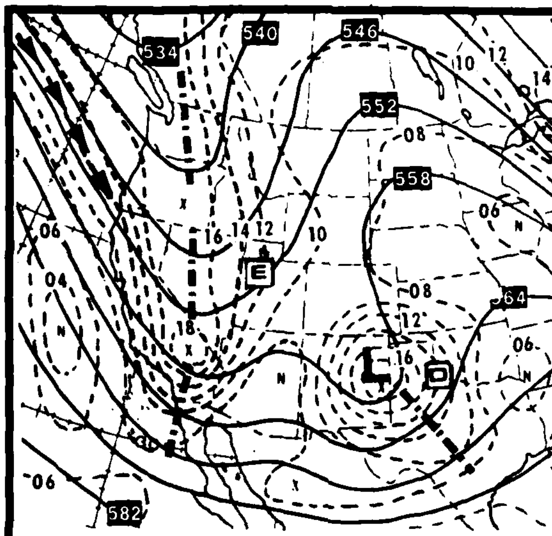


Figure 162: 500MB Height Vorticity Analysis 0000Z 10 April 1979

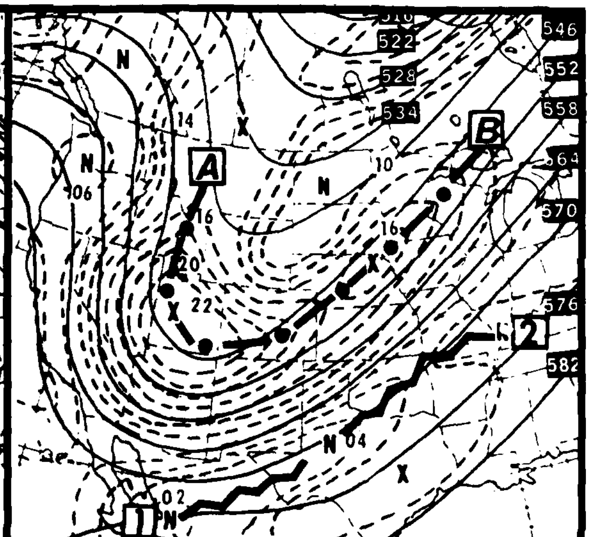


Figure 163: 500MB Height Vorticity Analysis Shear Lobes

• Shear Lobe - a "shear lobe" is a vorticity lobe whose axis crosses the height contours at very small angles or is paralleled to it (related to channeled jets). In Figure 163, lobe "A-B" is a shear lobe of maximum vorticity (even though the very small segment near A is not quite paralleled to the contours). The lobe is on the cyclonic shear side of the maximum wind zone. In Figure 163, lobe "1-2" is a shear lobe of minimum vorticity on the anticyclonic shear side of a strong wind zone. Note that it is the axis of the shear lobe which is parallel to the contours, not necessarily the vorticity isopleths. Few clouds are associated with these systems.

There is a certain cloud system observed in satellite pictures which appears as an unorganized cloud pattern on Day 1 only to evolve into a full scale comma cloud system by Day 2. This cloud system is appropriately nicknamed the baroclinic leaf - because of its overall leaflike appearance. In this section, leaf characteristics, patterns and evolution from leaf to comma will be presented. Also, relationships between leaf systems and synoptic features will be shown.

Characteristics:

A baroclinic leaf is a cloud system associated with frontogenesis aloft within a westerly wind flow. Usually, the system is vertically deep and surface frontogenesis and possibly cyclogenesis are also occurring. Because it is a thick cloud system, it is easily seen on both visual and IR scans.

The baroclinic leaf usually has an elongated pattern with well defined borders on both sides as illustrated in Figure 164. (Note: Baroclinic leaves are best defined in high amplitude trough patterns.) The poleward side frequently has a shallow "S" shape as shown in Figure 164. The upstream end has cyclonic curvature (location S in Figure 164) while the downstream end has an anticyclonic curvature appearance (location T). The anticyclonic end eventually becomes the comma head. Often, a telltale sign (and the first sign of comma development) is a "V" notch forming on the western edge of the leaf as noted at point W in Figure 164. The "V" notch is caused from the jet stream (and wind maximum) digging into the western end of the cloud system as noted in Figure 164.

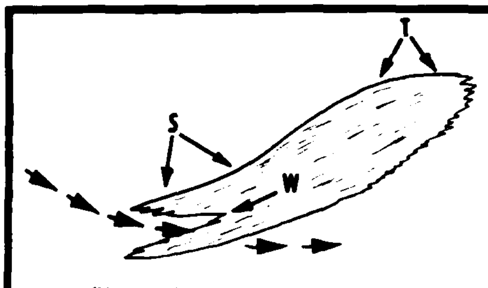


Figure 164: Baroclinic Leaf
"S" Shape and "V" Notch

Figure 165 depicts a model baroclinic leaf and its relationship with several upper level and surface features. Figures 166 through 168 are included to reinforce the discussion which will be shown in Figure 165. Note: In Figures 166 through 168 (valid at the same hour), the same leaf system is shown with each analysis. The features are:

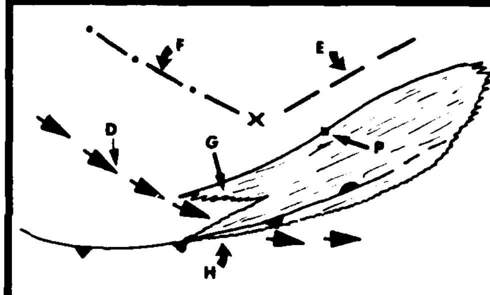


Figure 165: Baroclinic Leaf
Jet Stream and Vorticity Lobes

• Jet Stream - The jet stream axis is indicated by solid arrowheads in Figure 165. The jet stream upstream from the leaf (location D) is likely to be channeled with a maximum wind speed zone along it. Downstream, the jet axis is likely to be south of the leaf (and lesser wind speeds), but it may occur further northward. Figure 166 illustrates the 300mb jet stream relationship to the baroclinic leaf. A wind maximum of 130 knots is digging southeastward into the leaf system. A "V" notch appears - a reflection of the jet stream affecting the western end of the leaf.

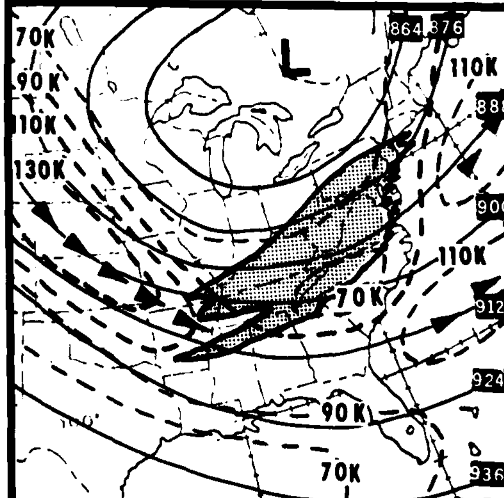


Figure 166:
Baroclinic Leaf/Jet Stream Relationship

• Vorticity - The vorticity center, noted as "X" in Figure 165, is located on the clear side of the upstream border near the inflection point (location P in Figure 165). Generally, two vorticity lobes intersect at the vorticity center (X) and form a rough L-shaped pattern as shown by the dash-dot and dashed lines in Figure 165. The dashed line (base of the "L" pattern) is usually an advection lobe (location E) and is parallel to the leaf. A region of packed vorticity isopleths (with PVA) is over the leaf pattern; this is shown in Figure 167 (isopleths are thin dashed lines).

Returning to Figure 165, the other lobe - a shear lobe; location F - forms the stem of the "L" pattern. This area is in a channeled configuration and is parallel to the upstream jet stream (location D in Figure 165).

The interrelation between these vorticity lobes and the baroclinic leaf can be seen in Figure 167. (Note: The solid lines are the 500mb contour flow.)

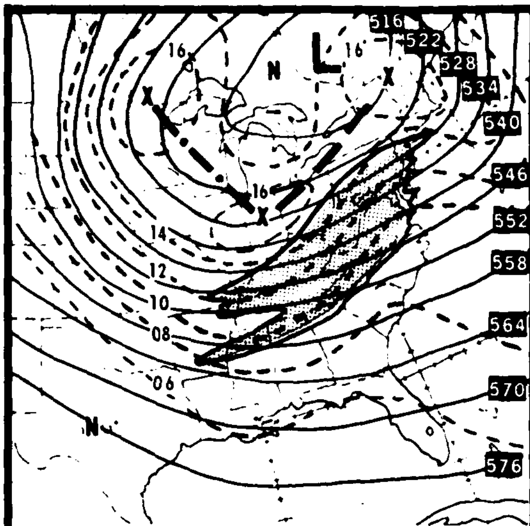


Figure 167:
Baroclinic Leaf Vorticity Relationship

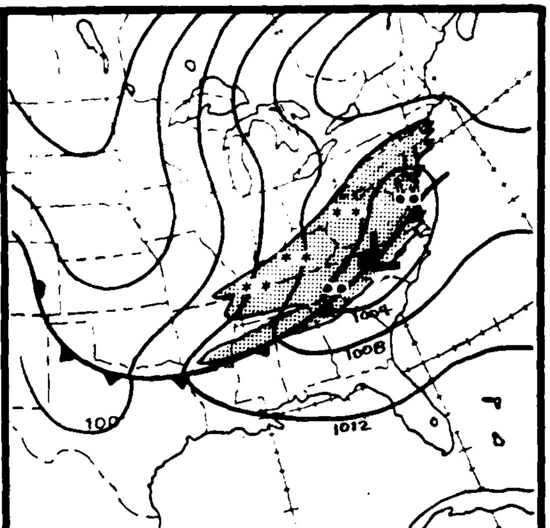


Figure 168:
Baroclinic Leaf Clouds and Frontal Relationship

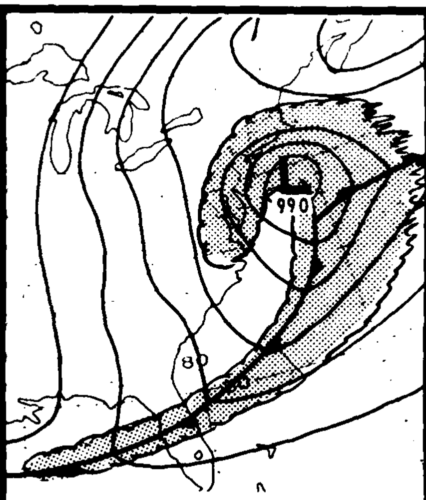


Figure 169: Comma System

Figure 170: 1946Z 27 November 1979

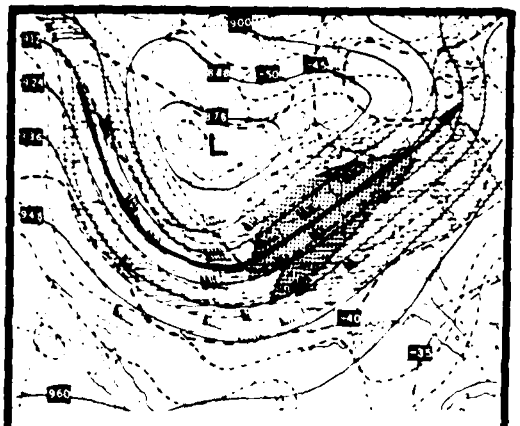
• Clouds and Fronts - Generally, the highest cloud tops are located over the eastern portion of the leaf. (Note: The eastern end will become the comma head.) The cloud tops decrease westward with middle level tops appearing over the western end of the "V" notch's northern border (location G in Figure 165). The southern border of the notch is composed of low clouds (excluding CB's; location H, in Figure 165) and lie along the cold front segment.

In Figure 165, the newly forming cold front would be located along the southern border of the leaf as shown in the illustration. The eastern end of the frontal segment (located under the deeper part of the cloud system) is likely to be stationary with a disorganized surface pressure pattern. A surface trough may exist instead of an identifiable frontal system. Figure 168 typifies the cloud/frontal/precipitation relationships with this particular leaf system.

Twelve hours later, Figure 169, the baroclinic leaf has evolved into a comma pattern.

• Example - Let's examine a case event of a baroclinic leaf system; satellite photos and conventional data are included in Figures 170 through 177. This example does not exactly follow the models shown earlier, however, forecasters should be able to recognize some of the more important features. NOTE: The baroclinic system shown in the satellite picture, Figure 170, has been superimposed on the four analyses (Figures 171 through 174) which will follow. Keep in mind that there is a seven hour difference between the baroclinic leaf system and the analyses.

At the beginning of this event, Figure 170, a pronounced leaf system appears over the central Midwest. The system is elongated and has well defined borders. A "V" notch appears over the western end which reflects the jet stream axis aloft (long white arrow). Low-level Gulf moisture has advected into the system across eastern Texas and Louisiana.



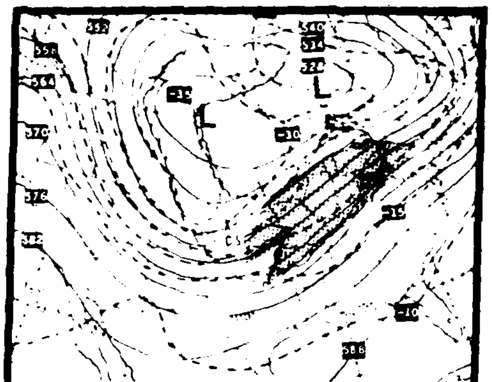


Figure 172
400MB 1200Z November 1979

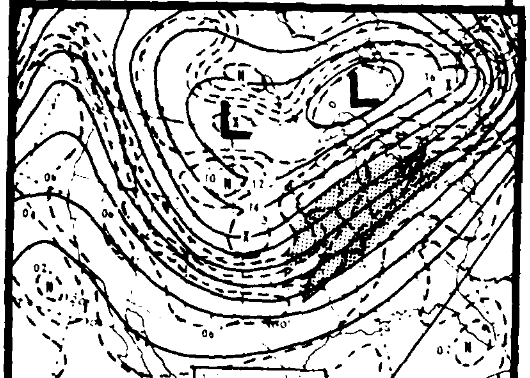


Figure 173
500MB Analysis Heights Vorticity

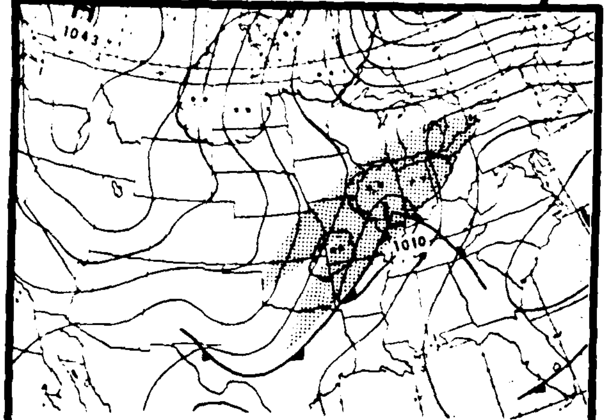


Figure 174: Surface 1200Z 27 November 1979

Figure 175: 0017Z 28 November 1979

Figure 176: 1616Z 28 November 1979

Figures 176 through 178 depict subsequent comma cloud development the following morning. In Figure 176, the comma head is located over the northeastern U.S. and is not shown in the photo. The cold frontal cloud band is evident across the southeastern U.S. and into the western Gulf of Mexico. The 500mb analysis, Figure 177, shows the deepening trough system. Two height fall centers are noted by X's; the centers closely approximate the location of two vorticity centers. The 500mb height fall center, previously located over western Kansas 12 hours earlier, has moved into southern Michigan and appears as a -22 center.

Finally, in Figure 178, an organized storm system appears over the eastern U.S. - its birth began as a baroclinic leaf the previous day.

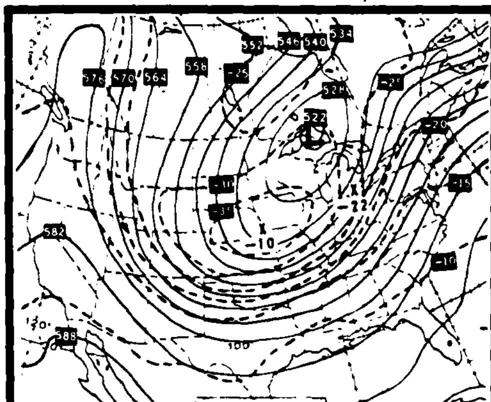


Figure 177:
500MB 1200Z 29 November 1979

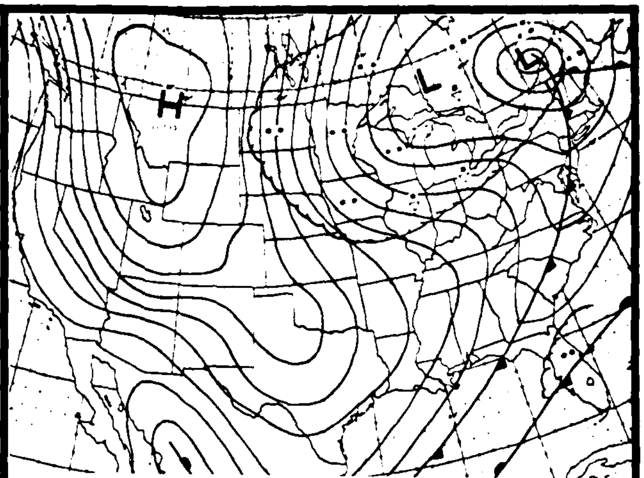
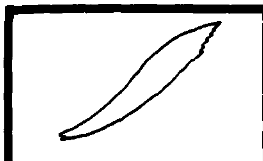
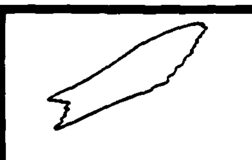
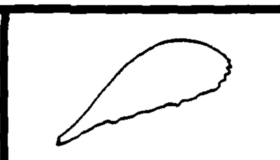
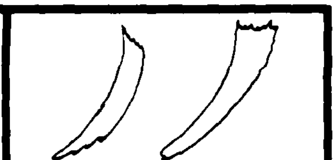


Figure 178: Surface 1200Z 29 November 1979

Patterns:

There are many variations, large and small, in the shape of leaf systems. Some are long and narrow, some have a much longer cyclonic and anticyclonic curvature along the poleward side (a longer "S" shape) and some are fat with the anticyclonic portion appearing as an arch shape. Figure sequence 179 depicts some examples of leaf configurations and have been empirically related to specific features of the wind flow. A brief description of the upper level pattern and related wind flow is shown below each figure (after Weldon, 1979).

			
The upstream jet is cyclonically curved and the channeled portion is likely to be relatively short. The pattern is often located at the base or on the front side of a relatively high amplitude trough. The jet axis is more likely to be near the tip on the downstream end.	*The upstream jet is likely to be relatively straight with a long channeled region. This is seen most in a low amplitude trough, in a zonal flow pattern or on the back side of a long wave trough.*	*These occur in a long wave shallow ridge, or when an old surface frontal zone is involved. The mid level ridge amplifies rapidly. Weldon refers to this type as a baroclinic "arch".*	*Pattern 179d (a crescent shape) and pattern 179e (a cyclonically bent torch shape) are found in the baroclinic zone around a closed low. There is no inflection point or convex part on the cold side border. Although these patterns are quite different in shape to most other baroclinic leaf systems, they have the same relationships to frontogenesis, precipitation increase, and wind field features. They form in the left front quadrant of a speed maximum coming around the parent closed low aloft.*
Figure 179a	Figure 179b	Figure 179c	Figures 179d/e

Evolution:

A baroclinic leaf evolving into a comma cloud system may take some time to change. Or, it may be fast. Forecasters, using half-hour GOES scans, may not immediately notice the change that is occurring within the leaf system. They must review previous pictures over several hours to detect these important changes.

Figure sequence 180 shows a well defined baroclinic leaf pattern at 1200Z which changed into a comma pattern by 0000Z. The sequence was taken from actual IR photos; the highest IR tops are indicated as the unshaded areas (white areas) in each illustration.

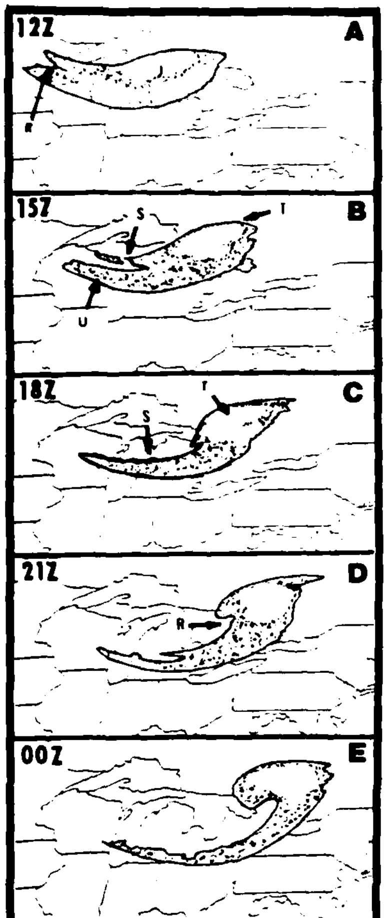


Figure 180: Evolution of a Leaf System to a Comma System

In Figure 180a, 1200Z, the first sign of comma development is a "V" notch forming on the western edge of the leaf (location R); note the "S" shape configuration of the poleward border. By 1500Z, Figure 180b, the [illegible] portion of the [illegible] boundary (location S) has begun to dissipate while the anticyclonic portion remains well defined (location T). [illegible] frontogenesis is occurring along the western end of the southern border (location U).

By 1800Z, Figure 180c, [illegible] of the northern border (location S) has dissipated leaving a [illegible] ragged edge to the tail part of the [illegible]. As the [illegible] narrows and the slot forms [illegible] the transition [illegible], the surface low begins to deepen. The anticyclonic [illegible], location T, is beginning to take on the appearance [illegible].

Three hours later, Figure 180d [illegible] and the "V" notch (dry slot; location R) [illegible] as it invades the [illegible] edge of the system. [illegible] a comma cloud system has taken shape. The surface [illegible] (not shown) has become well organized as it continues to deepen.

• Example - The following satellite photos (Figures 181 through 183) depict comma cloud development from a baroclinic leaf over a 16-hour period. In Figure 181, the "V" notch [illegible] seen in the IR scan at location D over Minnesota. Part of the northern boundary has begun to dissipate ([illegible] Figure 180b) and is shown at location E. Note: In suspected baroclinic leaf events, forecasters should look for these "V" notches within the mid and upper tropospheric regions - frontogenesis aloft is occurring at these levels.

Ten hours later, Figure 182, the visible [illegible] a frontal wave over the Lake Superior area. Finally, in Figure 183, (approximately 18 hours later from Figure 181), a well defined comma cloud can be located between the Great Lakes and Hudson Bay; the comma head (F) is well defined while the comma tail (G) is faintly visible due to its lower cloud structure.

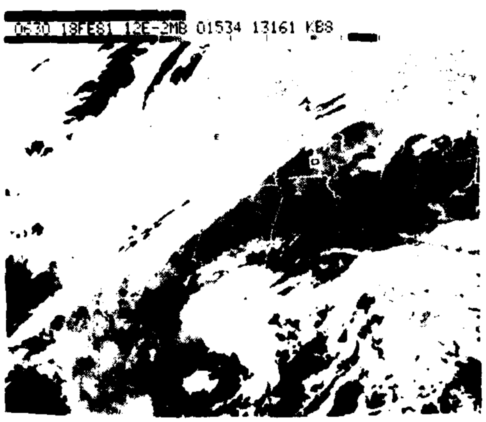


Figure 181: 0630Z 18 February 1981

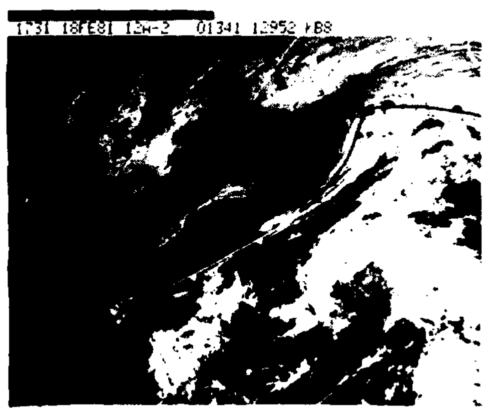


Figure 182: 1731Z 18 February 1981

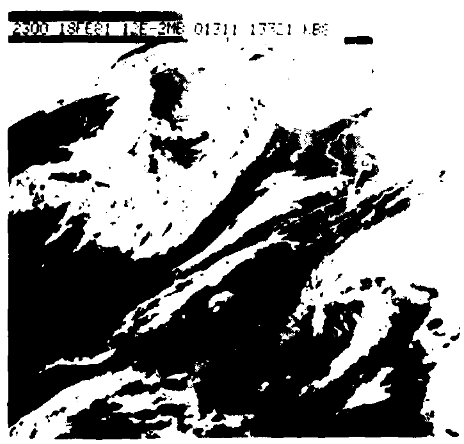


Figure 183: 2300Z 18 February 1981

• Other Signatures - The preceding figures depicted classic examples of leaf to comma evolution over a short period of time. The "V" notch was apparent indicating the presence of the upper level jet. Not all leaf systems will have the "V" notch signature; several of these non-"V" notch systems were shown earlier as leaf patterns (Figure sequence 179). An example now follows:

Figures 184 and 185 depict a leaf pattern which evolved into a comma cloud system off the west coast of North America. In Figure 184, the cloud system appears as a fat cloud shield (A), and it closely resembles the model shown in Figure 179c. Ten hours later, Figure 185, a comma cloud system has evolved. This particular system did not have the familiar "V" notch at the western end, however, the strong cyclonic curvature noted by the arrow in Figure 184, indicates that the jet stream is punching into the system. The 300mb analysis, Figure 186, shows the jet stream pattern associated with the leaf system. The analysis did indicate that a jet maximum was occurring (over the data-sparse area) near the western end of the leaf system.

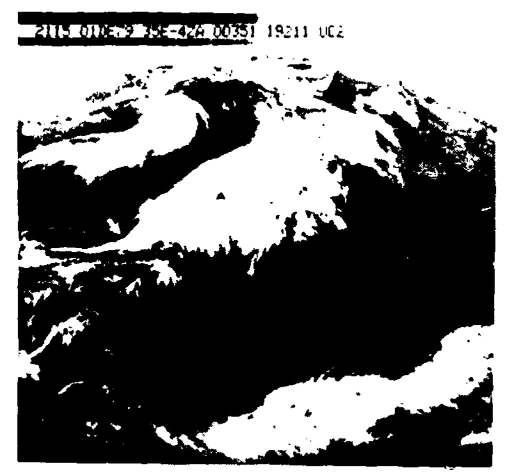


Figure 184: 2115Z 1 December 1979

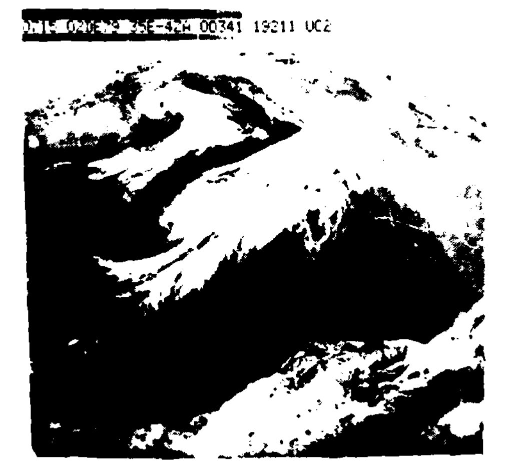


Figure 185: 0715Z 2 December 1979

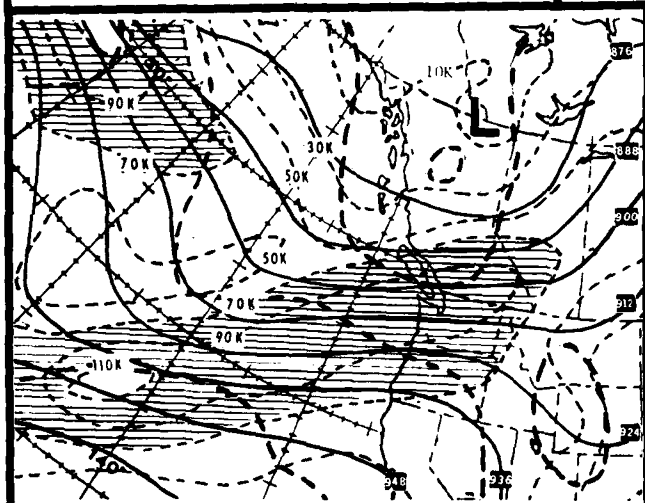


Figure 186: 300MB 0000Z 2 December 1979

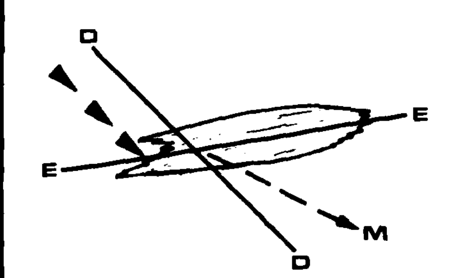


Figure 187:

Baroclinic Leaf Movement

Miscellaneous:

• Leaf Movement - A feature that helps in the recognition of a leaf cloud system is its direction of movement. Generally, it does not move in the direction of its orientation as shown along points E-E in Figure 187. Line D-D in Figure 187 parallels the axis of the channeled jet upstream. This stronger jet serves to push the leaf system southward (digging). The most likely direction of movement that the system will take is shown along the dashed line (M); it lies between lines D-D and E-E but closer to the line D-D (channel jet axis).

• Jet stream [illegible] - It has been shown throughout this [illegible] the ideal relationship between the jet stream and the developing leaf system. There will be those infrequent events where a leaf-like cloud system is apparent in satellite pictures, however, it will not evolve into a [illegible]. Figure 188 illustrates this event; the [illegible] has been included in the surface analysis.

[illegible] second [illegible] tion is located farther north of the "V" notch. Additionally, the jet stream speeds were significantly greater on the downstream side of the system [illegible] wind velocities should be less than the [illegible]. In this example a wide [illegible] area developed and surface frontogenesis [illegible], but the system did not evolve into a [illegible] pattern.

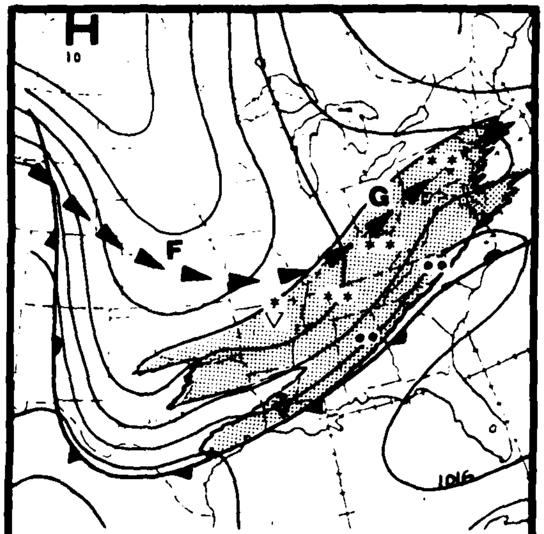


Figure 188:
Example:
Baroclinic Leaf, Now-Comma Development

Another event is shown in Figures 189 and 190 (IR and visible respectively). In Figure 189, a leaf-like cloud system appears off the west coast of North America. The jet stream lies poleward and parallel to the cloud system, therefore, it should not evolve into a comma cloud system. Thirty-two hours later, Figure 190, the leaf system is not apparent, however, an extensive baroclinic zone cloud band remains in the same general area as shown in Figure 189.

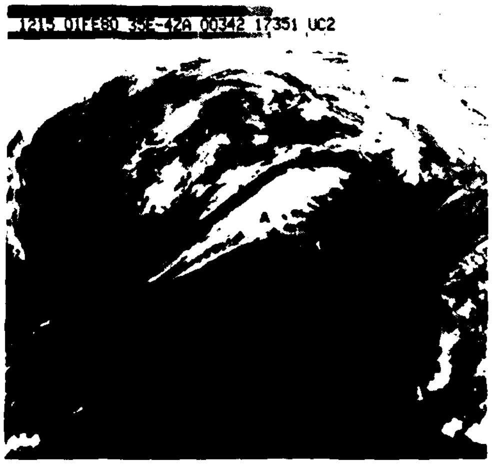


Figure 189: 1215Z 1 February 1980

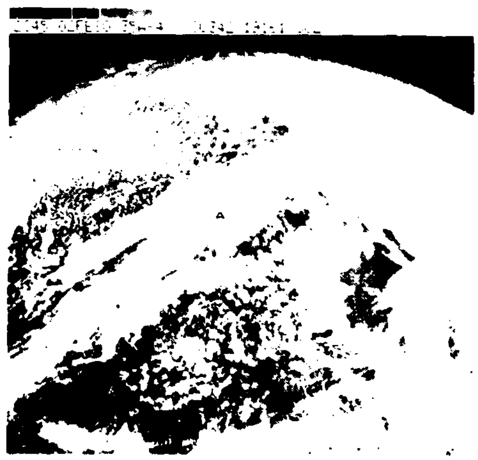


Figure 190: 2045Z 2 February 1980

[illegible] for the telltale sign of the "V" notch or a cyclonic "S" shape at the western end of the leaf system. [illegible] the satellite cloud system with the initial LFM vorticity analysis to see if vorticity [illegible] centers) really exist (500 mb height fall centers [illegible]. On the surface chart there should be signs of frontal waving and cyclogenesis.

Figure 191: 2130Z 17 March 1981

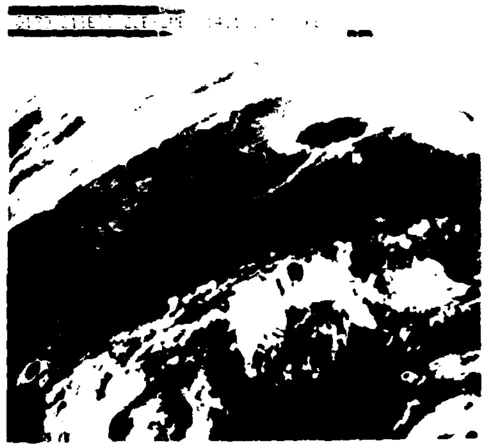


Figure 192: 0130Z 21 September 1980

Figure 193: 1816Z 14 April 1980

Comma Cloud Development:

Regardless of the comma size, whether it is a small vorticity comma or a large scale comma, the concepts of comma system development are similar.

• Differential Rotation - The comma shape of the cloud system is caused by distortion of the cloud mass due to rotation of the air around a center. If the system is not moving, the clouds will move with the rotating wind field as shown in Figure 194 and gradually develop a comma shape as illustrated in Figure 195. In this case, the low pressure center and the center of maximum vorticity will be the same. If the system moves eastward, the cloud system undergoes further distortion (see Figure 196). The area of maximum vorticity, denoted by the X, moves away from the lowest pressure denoted by the L.

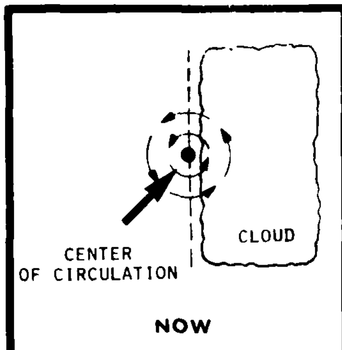


Figure 194

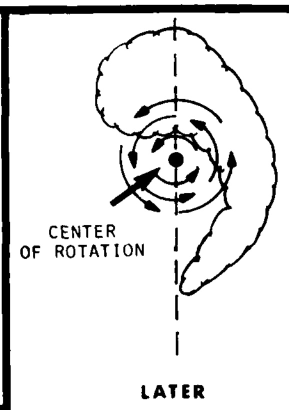


Figure 195

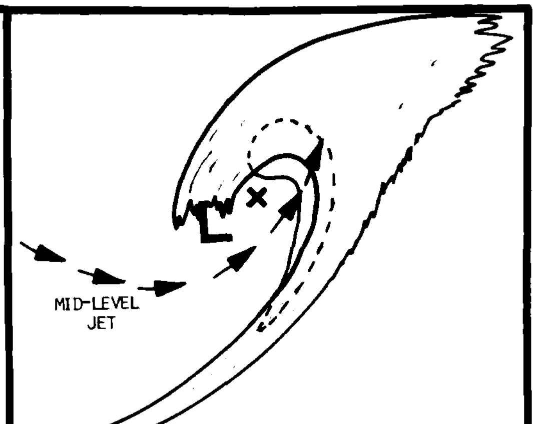


Figure 196

• Large-Scale Comma Cloud Development - An Example - The evolution of many large-scale comma cloud systems is much more complex that the theoretical model shown in Figures 194 and 195. (Note: One type of comma cloud evolution is the baroclinic leaf system which was presented in Section 3, Part II.) In this example, several disorganized cloud sub-systems may exist prior to the approach of the vorticity system. An example is shown in Figures 197 and 198. In Figure 197, several large cloud systems are noted. Baroclinic zone cirrus lies across Texas and the lower Mississippi Valley area. A closed upper low is noted by the L over the Four Corners; a deformation zone cloud band stretches north-south across Utah and Wyoming. Higher cirrus tops are shown across the upper Midwest and are occurring along an old frontal zone.

Approximately eight hours later, Figure 198, a large developing comma system appears over the Rockies and Great Plains. Rotation within the approaching vorticity center is noted across the central Rockies. The system intensified rapidly when it began to recurve toward the northeast and when Gulf moisture reached the system and began to release latent heat into the atmosphere.

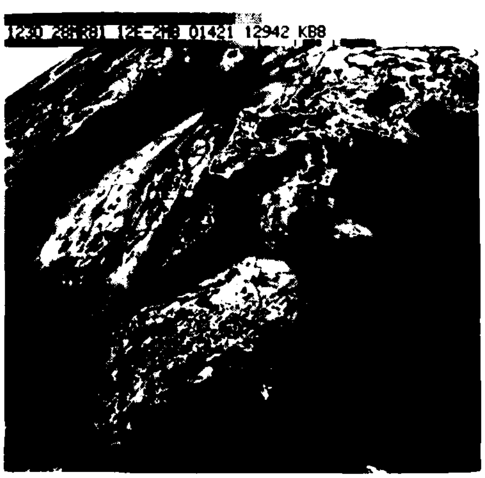


Figure 197: 1230Z 28 March 1981

Figure 198: 2100Z 28 March 1981

Comma Cloud Structure (General):

The following relationships apply to comma clouds in general - whether it be a small-scale vorticity comma cloud (mid-level system; *Figure 199*) or a large-scale comma cloud system as shown in Figure 200 (mid and high level system).

• "S" Shape - The most distinguishing feature in most comma patterns is the characteristic back edge of the comma. This edge - with its usual "S" shape, or inflection point and reversal of curvature (locations F in Figures 199 and 200) - is generally the best defined part of most comma patterns. The comma cloud will have a very distinct back edge (upwind), but the front edge (downwind) will be ragged as indicated at locations G in Figures 199 and 200.

• Comma Head - The comma head will be to the left of the axis of maximum winds in an area of large PVA (locations H in Figures 199 and 200). The comma head tends to lag and shows the most tendency for rotation.

• Surge Region - The surge region (locations F) is the dry intrusion of air into the comma. The surge region is located near the region of highest winds at a level near the cloud tops (dashed lines in Figures 199 and 200; excluding convective activity). The surge region in both examples shown in Figures 199 and 200 would be moving northeastward more rapidly while the part to the left (comma head) would be lagging and tending towards rotation.

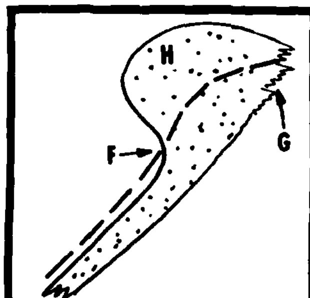


Figure 199:
Vorticity Comma Cloud

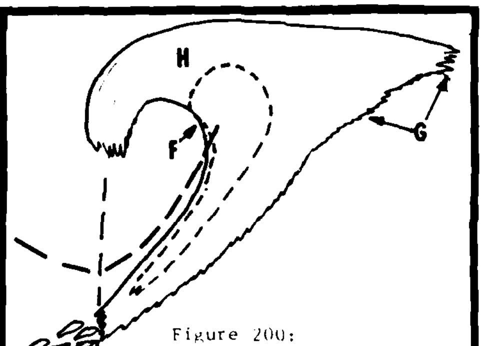


Figure 200:
Large-Scale Comma Cloud

• Comma Tail - The comma tail extends back from the surge region (locations F) to the south and becomes parallel to the axis of maximum winds at cloud top level (channeled jet) with the edge just to the right of the axis. Generally, a cold or occluded frontal system lies along the cyclonically curved portion of the comma (locations F) and down the comma tail. If the surface frontal system has not organized, weather (clouds, precipitation and convection) will be associated with the comma tail and not related to the location of the surface front.

Comma Cloud Structure - Deformation Zones (Synoptic Scale):

The streamline flow is respectively shown in Figures *201a (high levels) and 201b* (low levels below 700mb) within a mature comma cloud system. According to Weldon two deformation zones develop within these flow patterns. They are:

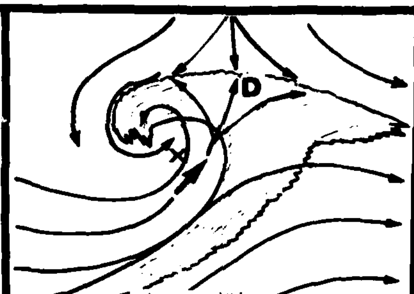


Figure 201a:
High Level Circulation

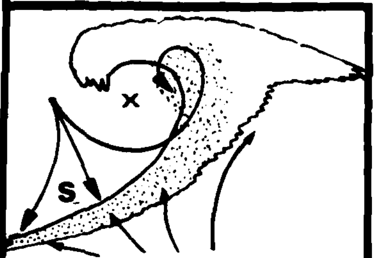


Figure 201b:
Low Level Circulation

• High Level Deformation Zone - In Figure 201a, clouds form and expand in the upward motion area (D) in advance of the vorticity maximum (X) and the jet *maximum* (heavy arrow). The air slows and undergoes difluence, some turning cyclonically around the upper low and others turning anticyclonically over the upper level ridge. At the top of the comma head along the converging streamlines, a distinct high cloud boundary develops. The clouds spread out in either direction (appears to stretch) and produces the comma configuration shown in Figure 201a.

In Figure 201b, the low level circulation center approximates the location of the mid-level vorticity comma cloud system. A cloud band, which forms the *comma tail*, lies along the converging flow as shown in Figure 201b. In the low level deformation zone (S), subsiding air decreases cloudiness, and the air generally becomes stable. The lowest cloud tops (excluding convection) within a comma system are generally located in the *comma tail*. Tops decrease significantly in the comma tail where the upper troughline intersects the tail (see discussion on page 30).

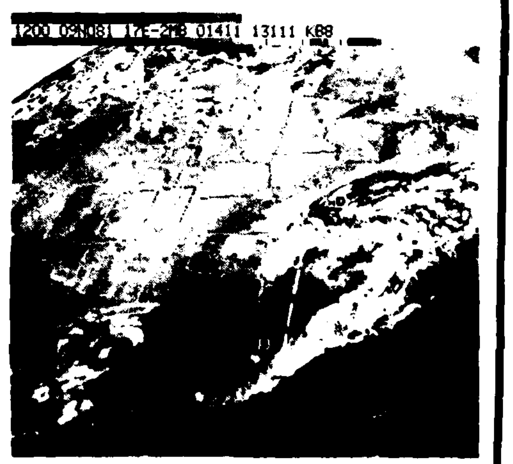


Figure 202: 1200Z 9 November 1981

The IR satellite photo, Figure 202, illustrates these points. In Figure 202, the high-level deformation *zone is indicated* across the area noted at D. The low level deformation zone is shown at S along the comma tail. Note that the higher level cloud tops end at the troughline, however, a lower level cloud band extends southwestward down the comma tail as marked by the arrows *in Figure 202*.

• Mid and High Level Jet Streams - The mid and high level jet stream enters the comma system in the surge region as noted in Figures 203a and 203b. The speed maximum lies upstream from the surge region as indicated by the closed dashed lines in Figures 203a and b. The high level jet may still be identifiable within a young comma system as shown in Figure 203a, but, as the comma system matures, Figure 203b, the jet becomes increasingly weaker (dashed line: increased warm air advection and ridging within the cloud system). Meanwhile, an intensifying jet stream either forms or strengthens along and parallel to the strengthening baroclinic zone (stronger temperature gradient) cirrus layer at the top of the comma head (east of the deformation zone (D)) as illustrated in Figure 203b.

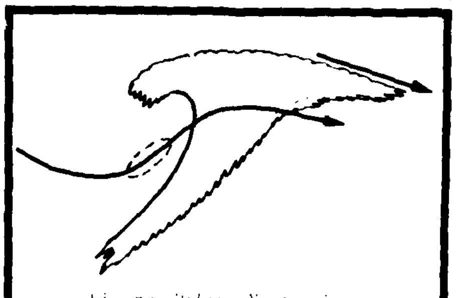


Figure 203a: Young Comma

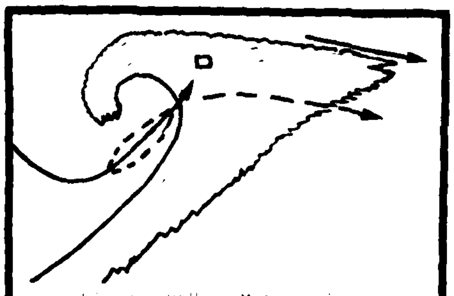


Figure 203b: Mature Comma

Empirical Relationship between Vorticity Advection and a Comma Cloud System - An Example:

Forecasters should be knowledgeable in placing comma cloud systems on AFGWC/NMC vorticity analyses and progs. Figure 204 depicts a typical comma cloud vorticity pattern empirical relationship. Each vorticity pattern is different: some will be small scale while others are very large. Some will be elongated across a large area and others will be either negatively or positively tilted.

In Figure 204, the cloud system should be located where the vorticity isolines (isopleths) cross the contour lines with the wind flow blowing from higher to lower values. This is the area of PVA (and the baroclinic zone). The strongest PVA area is where the isopleths cross the contours at the greatest angles; this area is noted at B in Figure 204. A good rule to use to locate maximum PVA is to find the smallest squares formed by the height contours and vorticity isopleths as shown in the region of B in Figure 204. If squares cannot be formed, locate the smallest parallelograms which are closest to the square. Note: The closer the contours are together, the stronger the winds will be; the closer the vorticity isopleths are together, the greater the vorticity gradient will be.

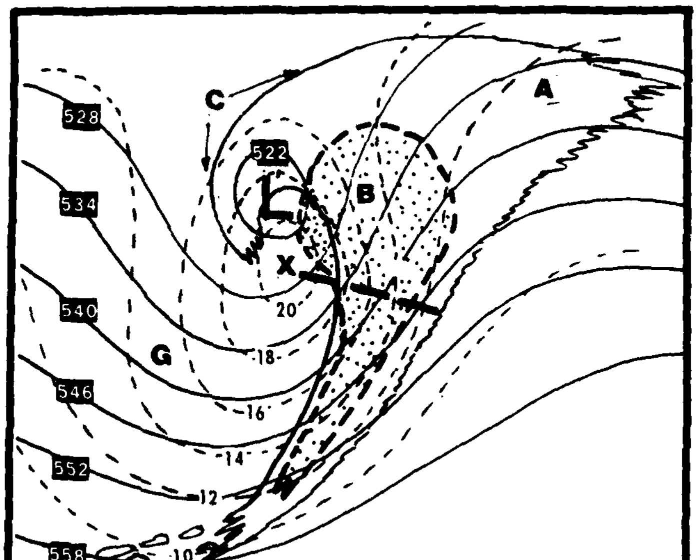


Figure 204: Typical Comma Cloud Vorticity Relationship

The vorticity comma cloud head (noted in region B in Figure 204), associated with a synoptic-scale comma system, lies within the area of maximum PVA. This area is the deepest part of the comma system, and where the lowest ceilings and heaviest precipitation would likely be occurring. The vorticity center noted at X in Figure 204, lies upstream from the comma head generally in a cloud-free area. Any clouds usually form further downstream where the vorticity gradient is stronger. Over ocean areas or at other places where cumulus clouds form behind the vorticity comma, rotation will be seen at the vorticity center.

The thick dashed line shown across the vorticity comma's surge region in Figure 204 denotes one of the axes of maximum vorticity and is the end of the area of maximum PVA. In this example, vorticity isopleths/height contour angles become increasingly smaller south of the axis and down the comma tail. The back edge of the cloud system should be located where there is no further crossing of the vorticity isopleths across the contours. The flow pattern behind the cloud system becomes channeled and eventually changes to negative vorticity advection (NVA: area G) in Figure 204 west of the troughline.

Each mature comma system's cloud structure is different, and it will not always resemble the model shown in Figure 204. Figures 205 and 206 illustrate two examples. The overall appearance of the system depends upon the configuration of the associated vorticity system - e.g., the strongest PVA area's orientation may become different than the PVA area (B) shown in Figure 204. Sometimes in mature comma systems, the rotation center pulls away from the circulation center to develop a new low further to the east; this is shown in *Figure 206*. The old, vertically-deep low will die and a new low will form along the baroclinic zone ahead of the approaching short wave vorticity comma (a common occurrence over the northeastern U.S.).
(Note: The three cloud sub-systems (A; B and C) shown in Figures 204 through 206 were presented on page 36.)

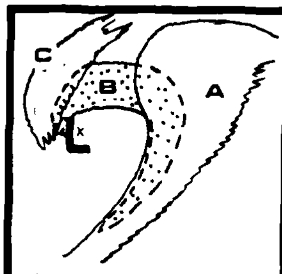


Figure 205: Example 1

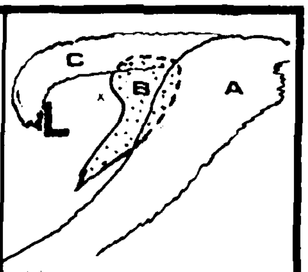


Figure 206: Example 2

Factors to Consider when Studying Comma Clouds:

A comma cloud system's overall pattern may change significantly within a short period of time, especially with rapidmoving short wave systems. Organized comma systems moving over the western U.S. from the Pacific Ocean (Figure 207) may become poorly defined in satellite pictures in just a few hours because moisture is depleted while moving across the mountains.

Infrared photos should be used to identify comma cloud patterns as shown in Figures 208 and 209. The temperatures at cloud top level should enable forecasters to determine how deep the system is. In Figures 208 and 209 (short wave systems), *the highest tops shown* in the comma systems over the central and western U.S. are in the -30 to -55°C range which would indicate cirrus tops to the 400mb level. (Use the Skew T to determine height.)

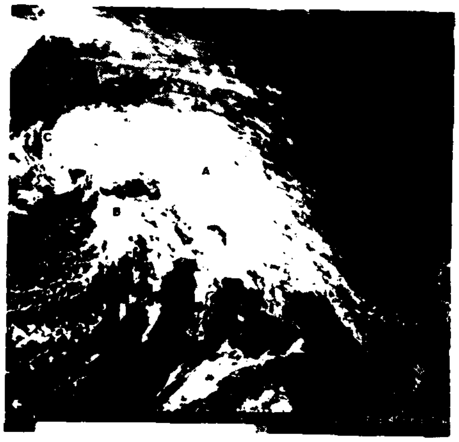


Figure 207: 0002Z 14 February 1980

Figure 208: 1400Z 24 November 1980

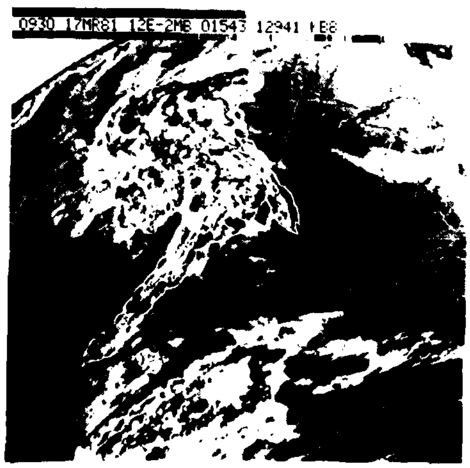
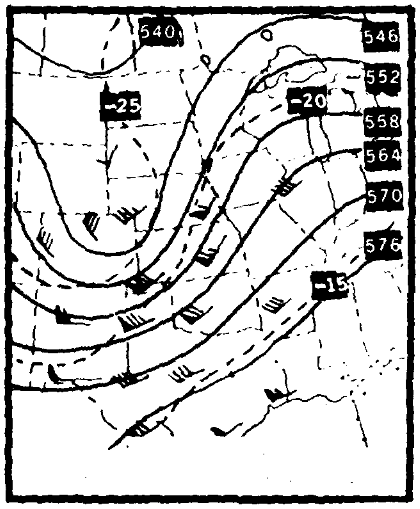


Figure 209: 0930Z 17 March 1981

[illegible]



[illegible]

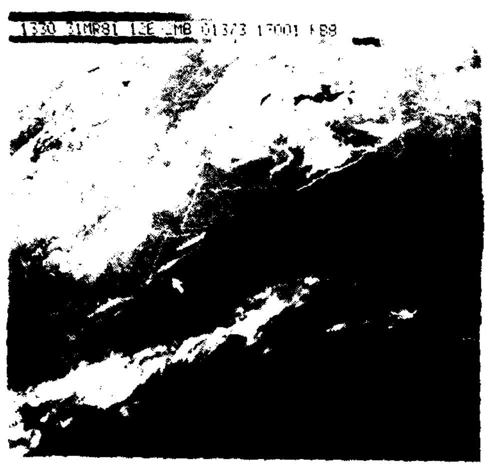
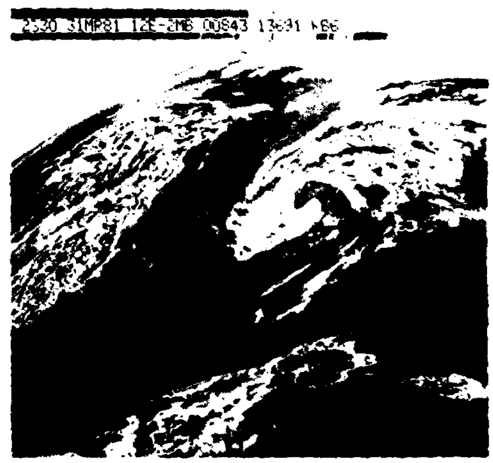


Figure 211: [illegible] 31 March 1981



[illegible]

Probably the best indicator of the strength [illegible] of the cloud system, not the overall size of the system [illegible] height of cloud tops involved. When a system [illegible] defined on all sides, however, the front side [illegible].

The shape of [illegible] cloud pattern [illegible]:

- the relative [illegible] stage [illegible] of the [illegible].

- which direction the related [illegible] vorticity [illegible] the pictures. Continuity on the [illegible] of the vorticity pattern [illegible] ated vorticity [illegible].

- [illegible] it is oriented.

- the [illegible] cloud pattern [illegible].

In the previous section most of the information that was presented dealt with the development and structure of synoptic-scale comma cloud systems. In this section we will look at smaller scale, short-wave vorticity systems which are not part of a large comma system. They often appear within the colder air air behind a larger, mature comma cloud. Or, a short wave vorticity comma may move into a stationary baroclinic zone to enhance frontal waving and cyclogenesis. These small comma systems may develop rapidly, and their interactions with large comma systems, with baroclinic zones and with moist, unstable zones, require close examination. Perhaps the selected examples included in this section will help forecasters to recognize some of the more common occurrences. Keep in mind while reading this section, that we will be discussing vorticity comma clouds which <u>are not</u> part of the main vorticity system located within the synoptic comma system.

Vorticity Comma Cloud Patterns (Figures 213,214,215):

The development and structure of vorticity comma systems were discussed in the previous section. The appearance of a secondary short wave vorticity comma cloud may take on many forms, especially during the developmental stage when it is moving southeastward towards the base of the main trough system. Initially, the comma may appear as a thin line, a blob, cluster or an elongated cloud band. When the vorticity center emerges from the base of the trough and begins to move northeastward (increased PVA), it will generally assume the shape of a comma cloud. The following three examples illustrate the most observed patterns of formation and development according to Miller (2). These patterns will be referenced, where appropriate, in the various synoptic examples that will follow later.

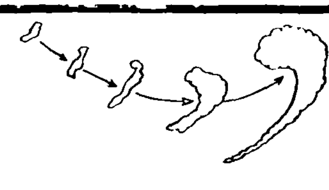


Figure 213: Classic Comma

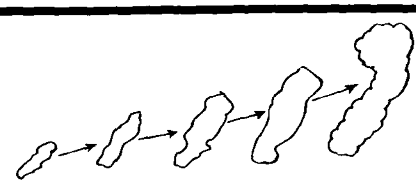


Figure 214: Blob or Band Comma

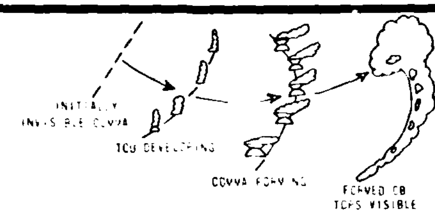


Figure 215: Invisible Comma

Pattern 1 - Figure 213 depicts the classic comma: it becomes increasingly well defined in the mid troposphere when it moves into an area of upward vertical motion and PVA (and in a zone ahead of which low-level frontogenesis is taking place).

Pattern 2 - Occasionally, a comma cloud will not attain the distinctive comma shape but will still initiate convective activity (and perhaps cyclogenesis) as it approaches and moves over favorable lower level features. This is illustrated in Figure 214.

Pattern 3 - When the mid and upper troposphere levels are too dry to support cloud formation, the comma will not become apparent until or unless thunderstorms develop (invisible comma; Figure 215). In these instances, conventional data must be used and close watch maintained for the first signs of line of cloud development on the satellite imagery. The activity is triggered by the approach of the PVA area over lower level moisture and stability fields. As thunderstorms develop, low-level moisture is transported upward, and in time, the comma shape becomes evident.

Synoptic Examples:

• Example 1 (Figures 216 and 217) - In satellite photos, smaller short wave troughs interacting with a large storm system often develop along the main troughline as noted by the arrow in Figure 216a. Several of these small commas may form and move eastward to produce increased cloudiness and precipitation for several hours behind the main system. On the surface analysis, Figure 216b, these secondary commas are reflected by showery precipitation (thunderstorms may occur if conditions are favorable) along and ahead of a wind shift trough. Each successive comma brings with it a new surge of precipitation, colder air and acccompanying gusty winds. Figure 217 reveals a springtime event; a small vorticity comma system (arrow) is rotating through an old mature system. The small comma is composed of thunderstorms.

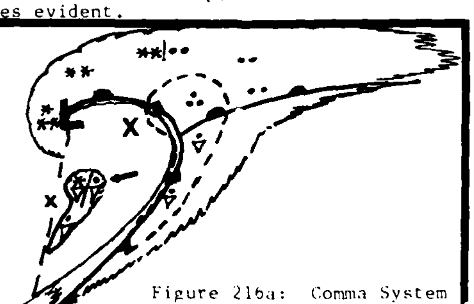


Figure 216a: Comma System

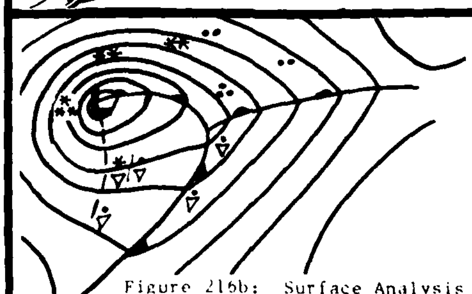


Figure 216b: Surface Analysis

Figure 217: 1500Z 29 March 1981

• Example (Figures 218 and 219) – The pattern shown in Figure 218 is frequently associated with upper-level troughs moving across the southern Rockies and Great Plains. In Figure 218, a large PVA area (A) develops over the Great Plains as large amounts of Gulf moisture move northward well ahead of the approaching trough system. In time, a vorticity comma cloud develops ahead of the vorticity maximum (B) over New Mexico or west Texas as increased moisture is encountered by the vorticity center. Generally, at the surface, a disorganized low pressure pattern with stationary frontal systems lie within the PVA area. Figure 219 shows an example: an ill-defined large [illegible] is located over the Great Plains, and a well-defined vorticity comma system (D) over New Mexico is approaching the storm system. Organization and intensification of the storm system can be expected (and often recurves toward the northeast) as the vorticity comma moves into the stationary PVA area. Let's look at a case study.

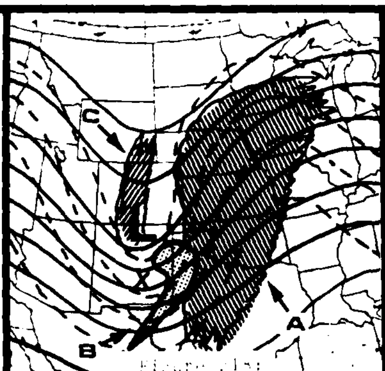


Figure 218:
Vorticity Comma
Approaching PVA area

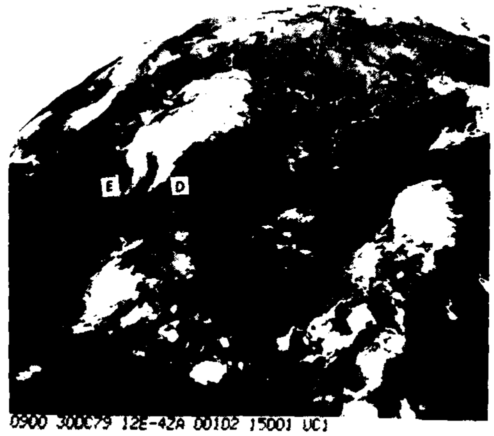


Figure 219: 0900Z 30 October 1979

• Case Study (Figures 220 through 229) – The 500mb analysis (Figure 220: height falls and the height fall center (X) are included) and the surface pattern (Figure 221) depict the synoptic conditions several hours prior to comma cloud development. In Figure 220, a short wave system is approaching the southern plains. At the surface, Figure 221, a large area of precipitation (PVA) within a disorganized pressure pattern is shown across the Great Plains.

In the first satellite picture of this series, Figure 222, (two hours later than Figures 220 and 221) a disorganized mid-level cloud formation, indicated by the arrow, appears behind the ill-defined, synoptic-scale comma system (and higher tops) over Texas.

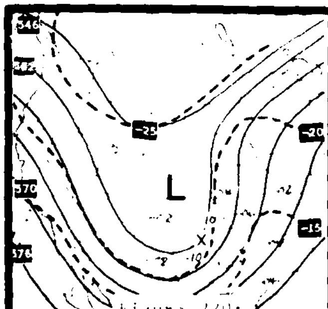


Figure 220:
500MB 0000Z 3 March 1979

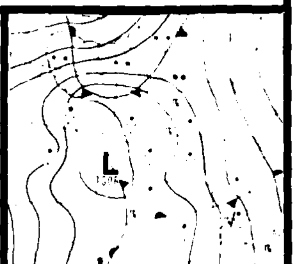


Figure 221:
Surface
0000Z 3 March 1979

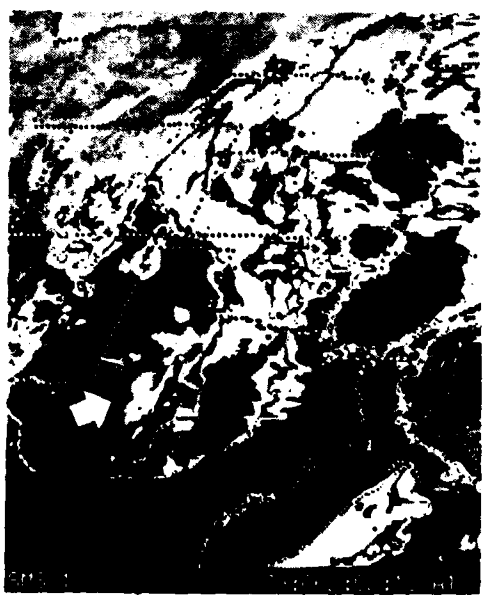


Figure 222: 0210Z 3 March 1979

Forty-five [illegible]

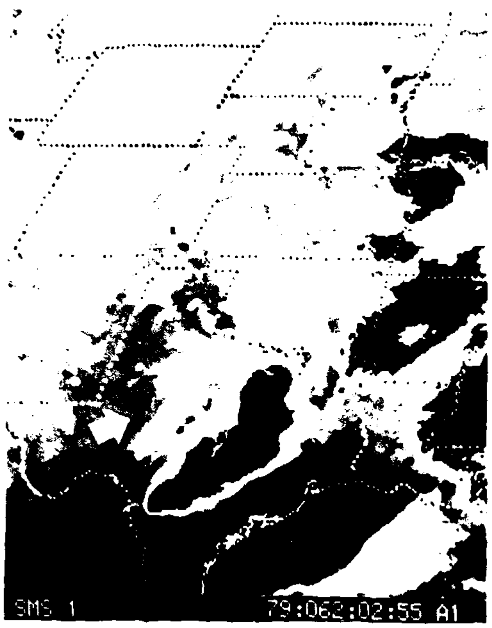


Figure 223: 0255Z 3 March 1979

Figure 224: 0355Z 3 March 1979

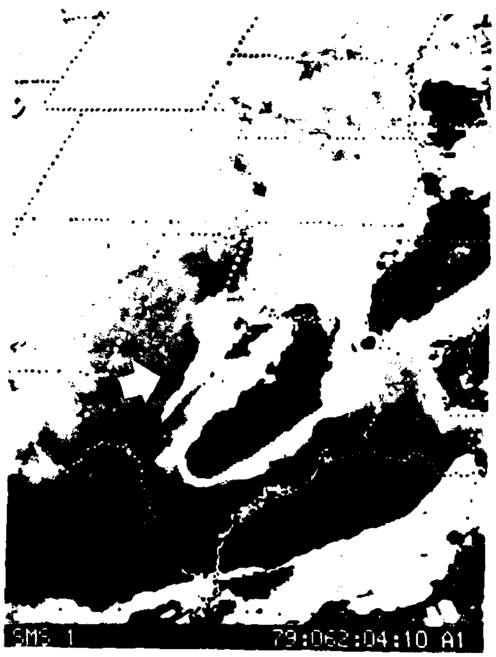


Figure 225: 0410Z 3 March 1979

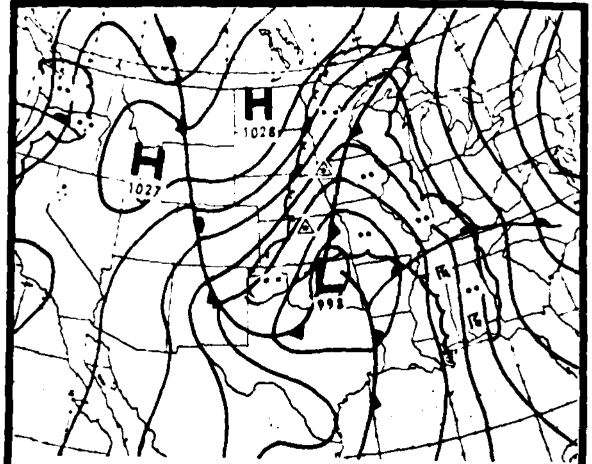


Figure 226: Surface 1200Z 3 March 1979

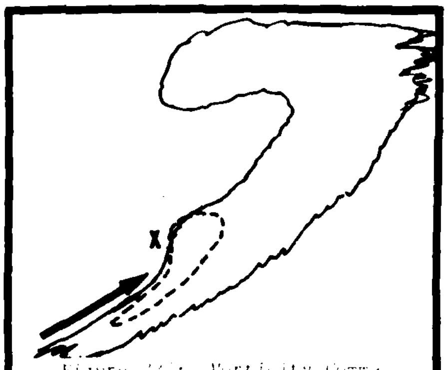


Figure 227: Vorticity Comma Developing within Comma Tail

• Example 5 (Figure 227) - This example, Figure 227, shows a vorticity maximum (X) moving across a comma tail to enhance cyclogenesis within a PVA area. Look for a "S" shape configuration developing along the west side (cold air side) of the comma tail as the vorticity maximum and jet speed maximum approaches the tail. A vorticity comma will develop beneath the higher level baroclinic zone cirrus layers unless the comma is formed by thunderstorm cirrus plumes; the following case study study depicts such an event.

• Case Study (Figures 228 through 231) - This particular example resembles the case study shown in Example 2 in several ways: an upper trough system is approaching Texas and the Gulf Coast and a large PVA area (becoming a synoptic-scale comma system) is evident across the south-central U.S.

Figures 228 and 229 respectively depict the 500mb and surface analyses 12 hours prior to vorticity comma cloud formation. In Figure 228, an upper low system is approaching Texas. The surface pattern (Figure 229) reveals the presence of an extensive high pressure zone across the U.S. Precipitation is occurring from central and west Texas westward to the Rocky Mountains - a reflection of increased PVA ahead of the approaching short wave system and upslope flow.

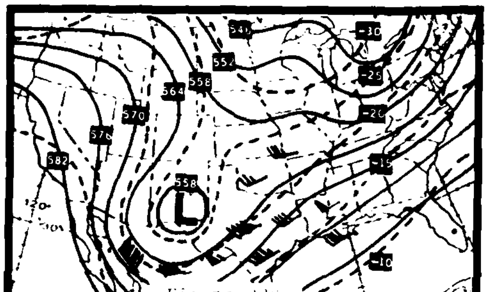


Figure 228: 500MB 1200Z 25 November 1980

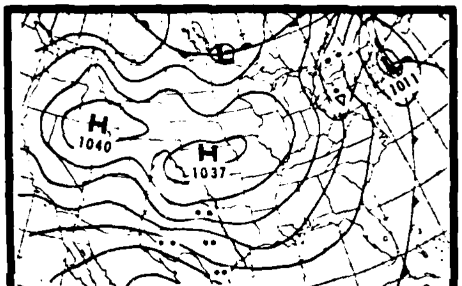


Figure 229: Surface 1200Z 25 November 1980

The first IR satellite picture of the series, Figure 230 (approximately four hours prior to comma cloud development and 12 hours later than Figures 228 and 229), a vorticity center noted at X over southern Texas is approaching the tail of a developing comma system located across the southern plains and lower Mississippi Valley.

Approximately four hours later, Figure 231 (note: different enhancement curve), the large area of PVA has become organized and has taken on a comma shape appearance. The apparent circulation center appears to be located over north-central Texas indicated by the L; the rotation center noted at X is shown off the Texas coast. The highest cloud tops observed (white in this particular enhancement) are apparently a result of thunderstorm plumes. A "S" shape along the cloud edge is apparent to the right of the X in Figure 231.

Figure 230: 2346Z 25 November 1980

Figure 231: 0316Z 26 November 1980

The subsequent series of satellite photos shown in Figures 232 through 234 reveal the lower [illegible] vorticity comma cloud system within the [illegible]. In Figure 234, note cirrus [illegible] over the eastern end of the comma head. (See Pattern [illegible] Figure [illegible].)

Figures 23[illegible] and 23[illegible] respectively [illegible] several hours after full vorticity comma [illegible] development shown in Figure 23[illegible]. In Figure 23[illegible], [illegible] is developing underneath the vorticity comma system shown in Figure 23[illegible]. [illegible] hours later, Figure 237, the organized storm system has moved northeastward [illegible] Valley area.


Figure 232: 0346Z 26 November 1980


Figure 233: 0416Z 26 November 1980


Figure 234: 0516Z 26 November 1980

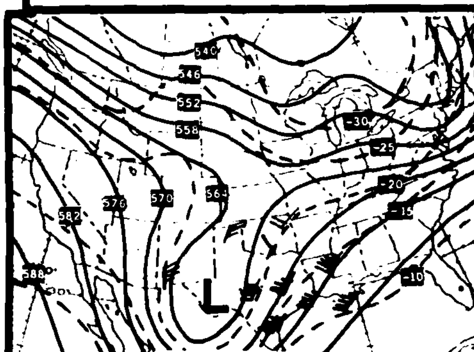


Figure 235: 500MB 1200Z 26 November 1980

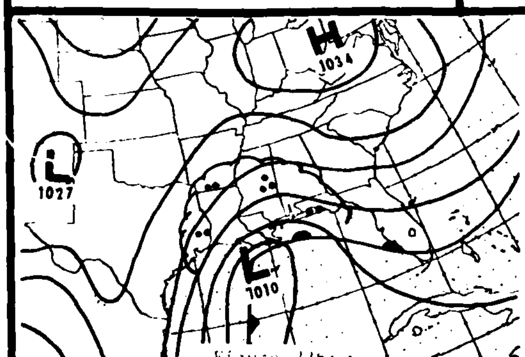


Figure 236: Surface 1200Z 26 November 1980

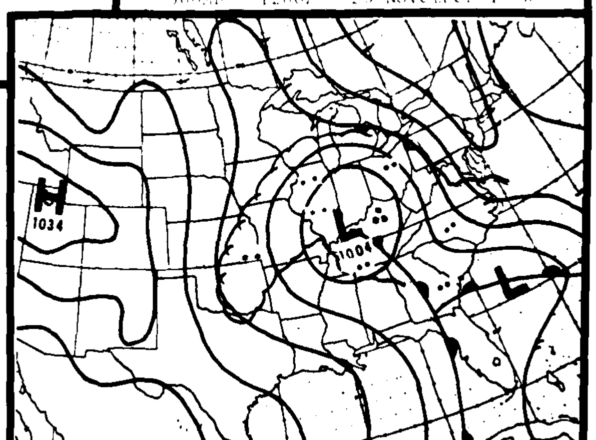


Figure 237: Surface 1200Z 27 November 1980

In this particular example, the vorticity center moved into the comma tail rather than the *comma head and triggered thunderstorms*. In previous discussions it was mentioned that, typically, the southern end of a comma tail has lower cloud tops excluding convection. The lesson learned in this example is that each system is different and the relationships between large comma and small vorticity comma systems will have many variations.

• Example [illegible] (Figure 238) - This pattern is common during the cold season across the eastern one-third of the U.S. when long wave trough systems prevail. Short wave systems, moving rapidly southeastward from central Canada across the Great Lakes area, induce waving and cyclogenesis along the older baroclinic frontal zone. (Note: This pattern and several other similar patterns will be shown in Part III, Patterns of Cyclogenesis.)

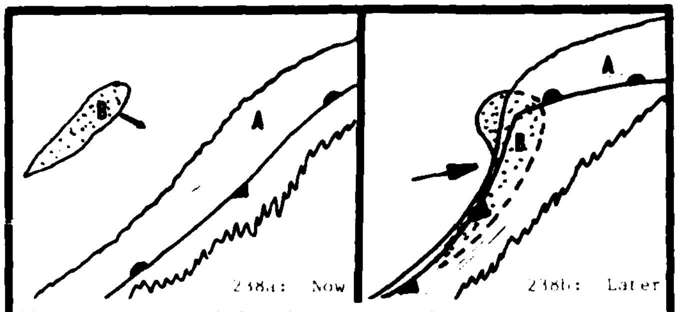


Figure 238: Vorticity Comma Approaching Baroclinic Zone

In Figure 238a, the approaching short wave's vorticity comma system (B) generally is not well defined as it moves southeastward towards the base of the major trough system. It may appear as a band, blob (or enhanced cumulus cluster) as shown earlier in Figure 214. The satellite picture, Figure 241, illustrates a band configuration of the short wave comma system (B).

Later, Figure 238b, as the vorticity center moves into the long wave trough, the comma becomes well defined, and induces a "S" shape (developing surge region noted by the arrow in Figure 238b) which produces frontal waving and cyclogenesis along the old frontal zone.

• Case Study 1 (Figures 239 through 241) - Figures 239 and 240 respectively depict the 500mb and surface analyses several hours prior to the satellite picture shown in Figure 241. In Figure 239, a long wave trough system is noted; short wave troughs would be difficult to locate within this particular pressure pattern. At the surface, Figure 240, frontal cyclogenesis has begun; the primary low for continued development is likely to be the Pennsylvania low. The satellite picture, Figure 241, shows a short wave comma cloud (B; see Figure 214) located over eastern Pennsylvania approaching the large baroclinic zone. This short wave system has induced frontal cyclogenesis; the short wave is reflected at the surface (Figure 240) by the secondary east-west trough system located across the Great Lakes.

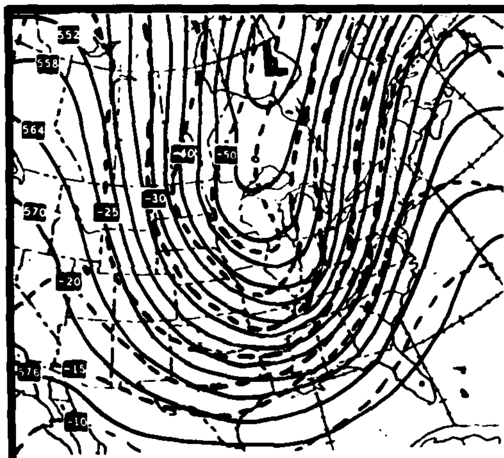


Figure 239: 500MB 1200Z 2 February 1981

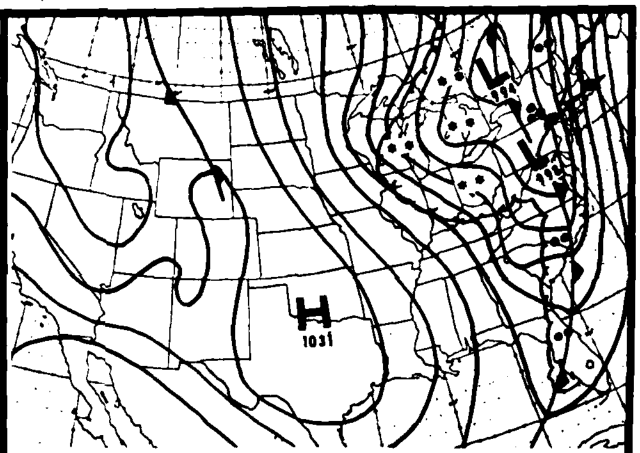


Figure 240: Surface 1200Z 2 February 1981


Figure 241: 1430Z 2 February 1981

• Case Study 2 (Figures 242 through 245) - In this example, the upper trough system is not as pronounced as the trough system shown in the previous example. The 500mb analysis, Figure 242, approximately seven hours earlier than the satellite picture shown in Figure 243, reveals a strong 500mb jet stream (75-80 knots) over the upper plains states moving southeastward towards the Mississippi Valley area. This jet maximum undoubtedly reflects a short wave within the flow, but it is difficult to find in Figure 242. The satellite photo, Figure 243, however, gives a clue of the short wave's presence - a developing comma cloud located over Illinois as noted by the arrow. At the time of the photo, the vorticity comma is composed mostly of a cluster of enhanced cumulus. Soon, it will move into the stationary baroclinic zone noted over Indiana and Michigan and eastward. Frontal waving has already begun as shown in Figure 243.

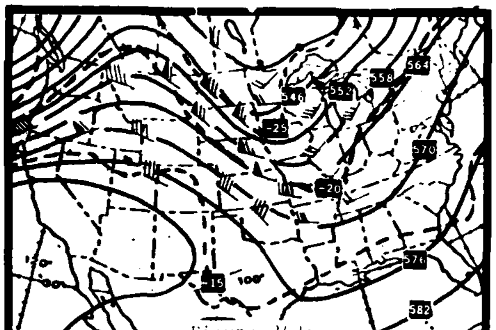


Figure 242:
500MB 1200Z 19 February 1981

Figure 243: 1930Z 19 February 1981

Figures 244 and 245 respectively show the 500mb and surface analyses the next morning. A 500mb closed low is shown over Ohio in Figure 244. In Figure 245, the upper low is reflected at the surface in central Pennsylvania.

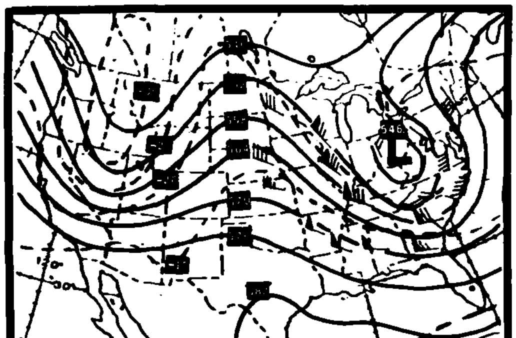


Figure 244:
500MB 1200Z 20 February 1981

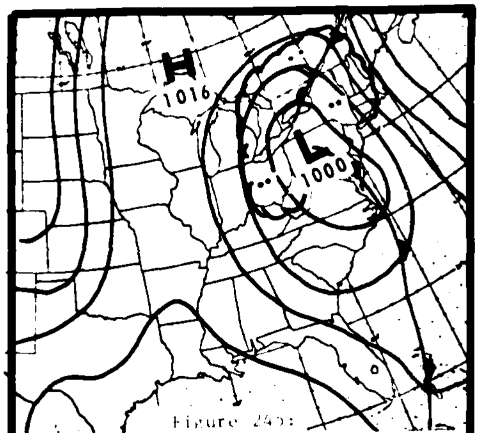


Figure 245:
Surface 1200Z 20 February 1981

• Example 5 (Figures 246 through 251) - During the warm season, weak trough systems (and weak vorticity centers) may have little, if any, mid and high level baroclinic cloudiness accompanying them. When the vorticity center moves into and over a moist, unstable area, convection develops. The anvil plumes may reveal rotation; this is shown in the following sequence of pictures.

Figures 246 and 247 respectively depict the 500mb and surface patterns during the morning prior to increased convection. In Figure 246, a weak low system is shown over the central Great Plains, however, it is not reflected at the surface in Figure 247.

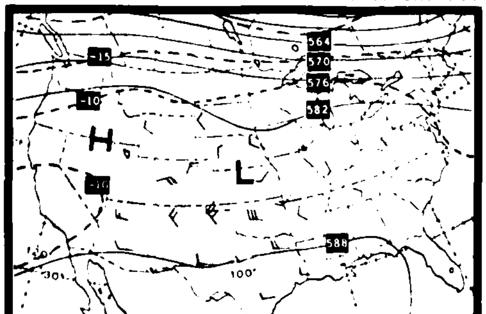


Figure 246:
500MB 1200Z 13 September 1981

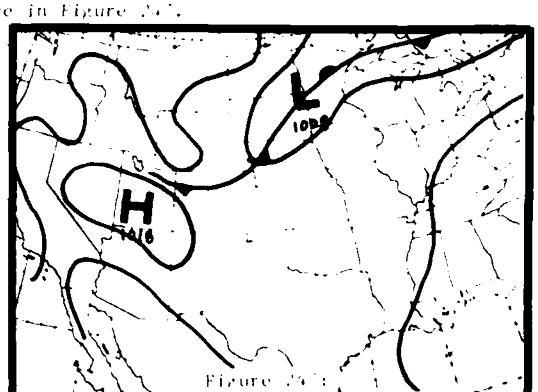


Figure 247:
Surface 1200Z 13 September 1981

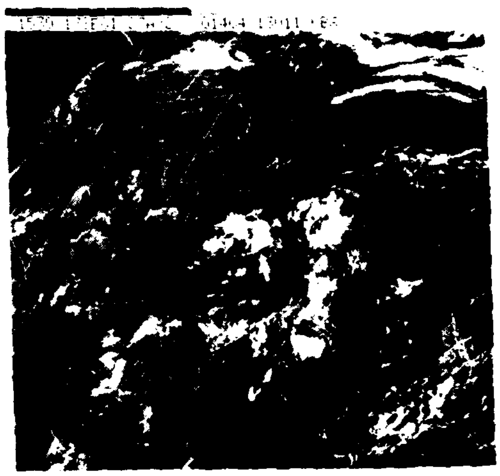


Figure 248: 1530Z 13 September 1981

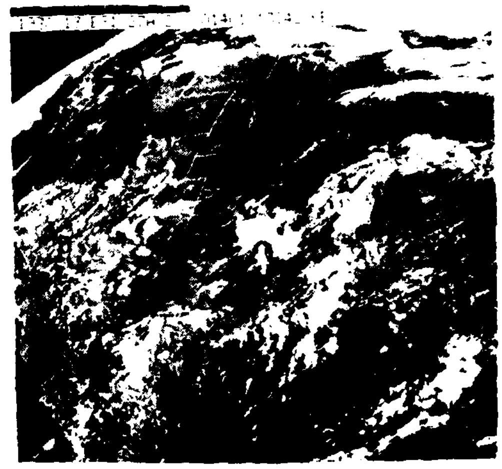


Figure [illegible]: [illegible] 13 September [illegible]

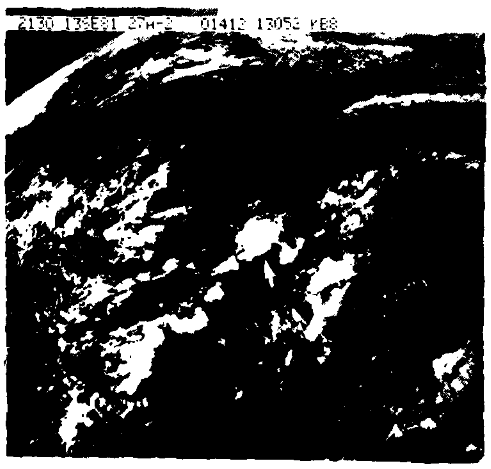


Figure 250: 2130Z 13 September 1981

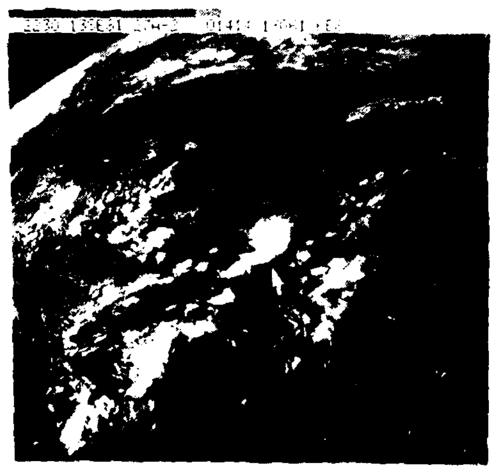


Figure 251: [illegible] 13 September [illegible]

Deformation zone cloud patterns associated with comma cloud systems were presented in some of the preceding sections. In this section additional deformation patterns and their usefulness in forecasting will be shown.

Deformation zones are neutral points in the atmosphere's motion relative to itself. Deformation zones are observed in the cloud motions and in the wind fields at all levels, and many seem to affect a very deep layer of the atmosphere: significant clouds and precipitation are associated with these zones.

In the upper atmosphere, these deformation zones may be found by subtracting the earth's rotation from the wind vector. In Figure 252, the shaded areas mark confluent zones where clouds form. The shape of these clouds depends upon the synoptic pattern, the amount of convergence and the availability of moisture. Figure sequence 253 illustrates some of the more common deformation cloud forms observed in satellite photos (of course, many variations and combinations of these patterns are likely).

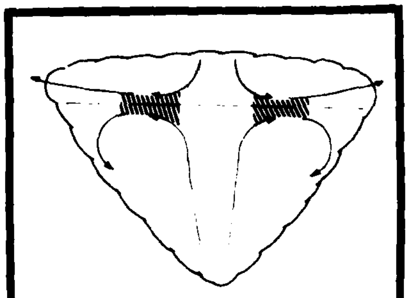


Figure 252: Confluent Zones

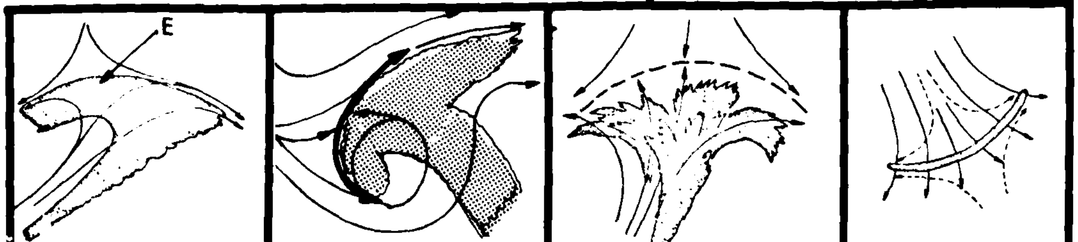


Figure 253a: Young Comma

Figure 253b: Mature Comma

Figure 253c: Fountain

Figure 253d: Band

Case examples (IR Photos):

The following IR case examples show several deformation shapes related to the patterns shown in Figure 253. Some conventional data is also included.

• Example 1 (Figures 254 and 255) - In Figure 254, the mid level cloud pattern shown over Kansas, Nebraska and the Dakotas resembles the fountain - like deformation zone pattern shown in Figure 253c. Some of the clouds curve cyclonically around a low in western Oklahoma (R: see white large arrow) while the other clouds curve anticyclonically around an adjacent ridge (S: see arrow). The 500mb analysis, Figure 255 shows the high/low pressure combination to produce this deformation pattern. In Figure 254, the deformation cloud band stretches eastward across Iowa to the Ohio Valley area - a reflection of the converging wind flow shown across Nebraska and Iowa in Figure 255.

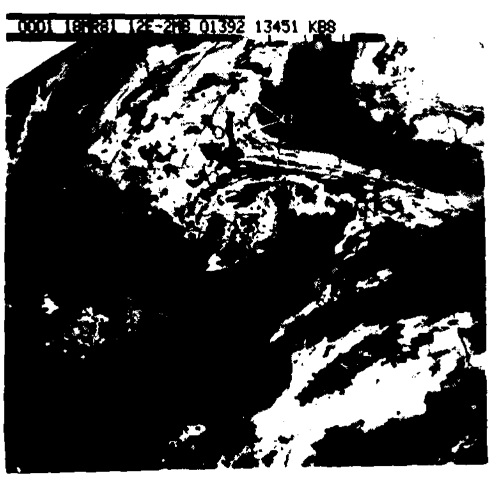


Figure 254: 0001Z 18 March 1981

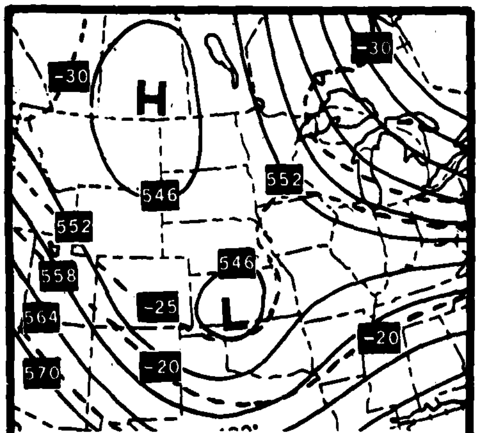


Figure 255: 500MB 0000Z 18 March 1981

• Example 2 (Figures 256 and 257) - The following example typifies a deformation zone cloud pattern associated with blocking patterns. The high system is poleward of the low. This pattern is observed off the West Coast during the winter season when blocking highs become established across Alaska and western Canada and adjacent ocean areas. Figures 256 and 257 illustrate this pattern. The 500mb analysis (Figure 256) depicts a blocking high in the Gulf of Alaska which has produced a fetch of cold Canadian air into the central U.S. plains. In Figure 257, a deformation zone cloud system, noted by the arrow, is located west of Oregon; it compares favorably with the deformation zone C pattern in Figure 253. Forecasters may use this cloud system feature as a tool in determining either the persistence or the breakdown of the blocking pattern. For instance, if the deformation cloud pattern shown in Figure 257 continues in subsequent photos, then there is no apparent change in the blocking high pattern. Conversely, if the deformation cloud system shown in Figure 257 begins to dissipate or shift to another area, the upper level changes are occurring.

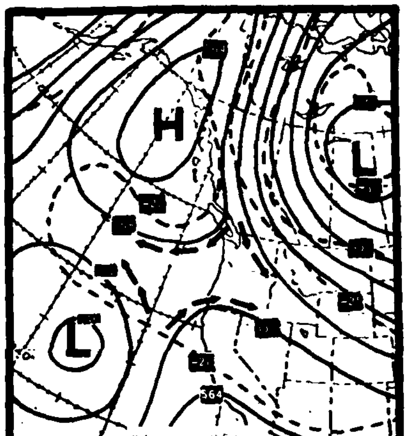


Figure 256: 500MB 0000Z 13 February 1980

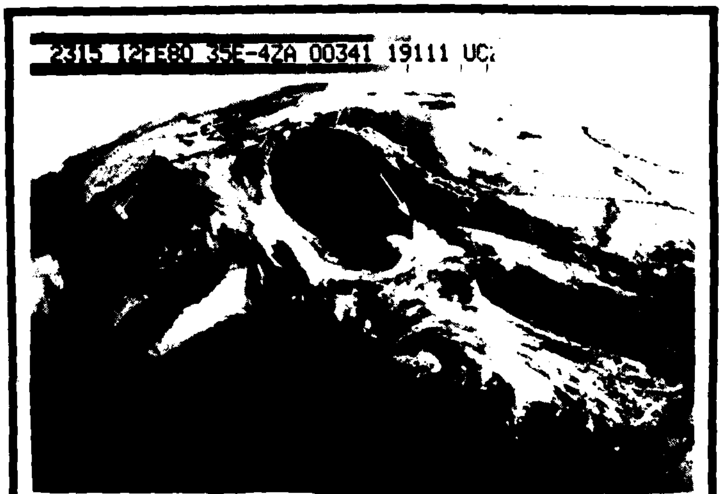


Figure 257: 2315Z 12 February 1980

Elongated Mature Comma Deformation Zone Cloud Bands (Figures 258 through 260):

Forecasters should pay particular attention to deformation zone cloud bands which stretch some distance upstream from the main comma system (see points C in Figure 260). In these cases, the associated vorticity comma and baroclinic zone cloud system continue to move eastward while the vertically-deep upper low lags behind. Eventually the old low dies and a new low develops further to the east. An *example follows:*

The 500mb and surface analyses (respectively Figures 258 and 259) portray the synoptic events during the morning hours. An upper closed low and its related surface storm are shown emerging from the southern Rockies. Two hours later, the satellite photo, Figure 260, reveals the cyclonic circulation of the storm system over Kansas and Colorado. This system's comma shape is somewhat ill-defined; the baroclinic zone (A) appears to have separated from the deformation zone cloud band (C) within the col area of the comma head over eastern Iowa. The vorticity comma system, noted at B, appears as a cloud band.

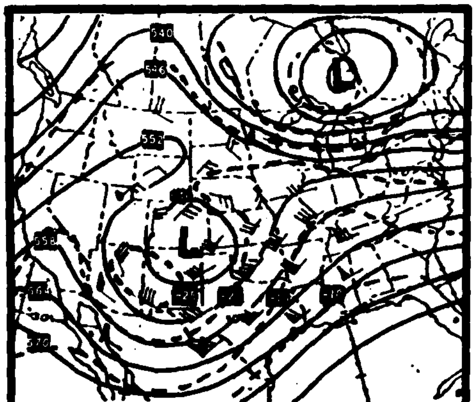


Figure 258: 500MB 1200Z 4 March 1981

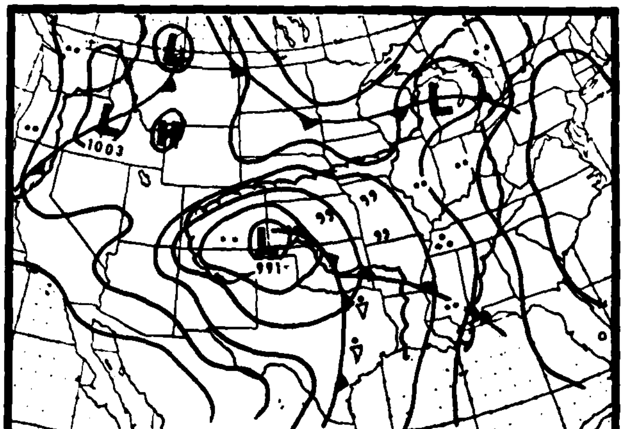


Figure 259: Surface 1200Z 4 March 1981

Figure 260: 1400Z 4 March 1981

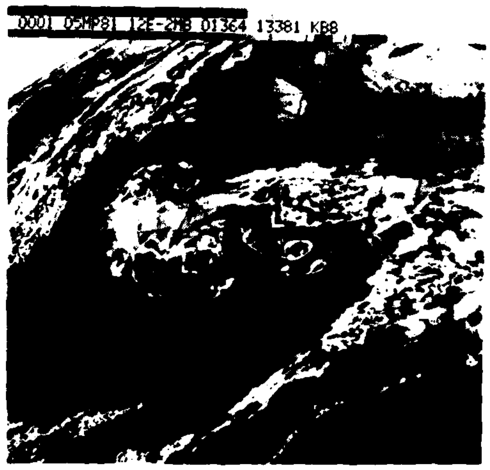


Figure 261: 0001Z 5 March 1981

The separation of these cloud systems and the long, stretched deformation zone cloud system noted between points C is an indicator that upper level changes are likely to happen. Ten hours later, Figure 261, two circulation centers are noted. The old center, marked by the dashed white L, is decaying while a new center is forming over southern Missouri (solid white L).

The above sequence occurs more often over the eastern U.S. Old, vertically-deep occluded lows over the Great Lakes slow down and fill while a new frontal storm system develops either along the East Coast or offshore (or a combination thereof).

Deformation Clouds Forecast Movement of Low:

Trying to forecast the short range motion of closed upper-air lows using upper air charts may be difficult; objective analyses often miss important details by being too smooth. However, satellite pictures can be of great help especially if a good band of deformation cloudiness exist upstream from the closed low.

The reasoning is: if a closed low exists, there is a splitting of the flow (deformation) upstream from the low. When the low center is essentially stationary, the deformation field will remain strong and the associated deformation cloudiness will persist. However, if the low center is on the move the deformation cloudiness will decrease with time (3).

(NOTE: Currently, investigations regarding significant turbulence within areas of upper level deformation zones are being done by NESS.)

GOES satellite data is one of the most powerful tools available to help forecasters isolate areas in which convective and severe convective weather is occurring and, in addition, can be a very powerful short range forecasting tool to the astute forecaster.

There really is no magic invo[illegible]ed. As you have learned in school, convective activity requires moisture, instability, an[illegible] trigger. This section will concentrate on helping the forecaster to search out the clues [illegible] ill lead to correctly forecasting thunderstorm outbreaks.

Upper Level Divergence:

Severe convective weather is frequently associated with a high level divergence zone between the subtropical jet and the southern branch of the polar jet (Figure 262). Since these two jet streams are at different levels, it is often hard to locate them both on the same constant pressure charts. The cirrus shields and bands shown in infrared photos are an excellent way to locate jet streams (see pages 20-27). Figure 263 illustrates this principle. A diffluent area between these jets encompasses an area from the central plains eastward to the East Coast. Thunderstorms are visible from Oklahoma to the Great Lakes as noted by the arrows. The diffluence/threat area shown in Figure 263 covers a large area; forecasters must still locate the most likely area where convection will fire (low-level moisture, instability, convergence, etc.) within these large diffluent areas.

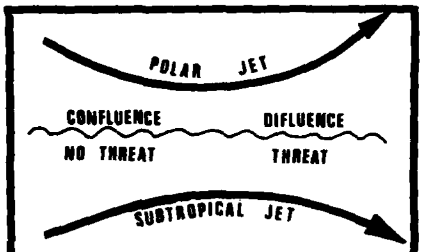


Figure 262: Threat/No Threat Areas

Figure 263: 2200Z 28 April 1981

Low-Level Convergence (Figures 264 through 269):

Many of the most severe outbreaks of convective activity occur along squall or instability lines which develop in the convergence zones in advance of cold frontal systems; an example is shown and noted by the arrow in Figure 264. The first activity usually develops on the western side of the low-level convergence zone and travels eastward. The reason for this is that the vertical motions are stronger here, the moisture content is highest here, and the solar insolation reaching the ground is greater in the clear air just to the west of this region. The convergent zone is usually visible, though it sometimes is quite far in advance of the cold front (see Figure 265). If the low-level clouds are visible, you will frequently see a wedge shaped zone of small cumulus clouds streaming south to north and perhaps spiraling towards the center of the advancing low pressure system. If a cirrus shield exists, forecasters may have to rely on the conventional wind data and stream line analyses to determine the areas of greatest low-level convergence and on dew point analysis to locate areas of greatest humidity to determine the most active regions. The degree of instability must be obtained from Skew-T charts.

Figure 264: 1730Z 17 May 1981

Figure 265: 2230Z 17 May 1981

Figure sequence [illegible] through 269 illustrate [illegible] convergence. In this sequence, [illegible] with extensive overrunning of the east-west warm front. [illegible] be seen advecting moisture from the Gulf of Mexico towards the [illegible] sequence. First thunderstorms occurred [illegible] the thunderstorms (Figure 266) are fully developed. [illegible] central Oklahoma into northwestern Missouri. [illegible] with arrows pointing to the area of maximum development. This line [illegible] eastward [illegible] the night and was evident in Arkansas on the [illegible] May [illegible] (Figure [illegible]).

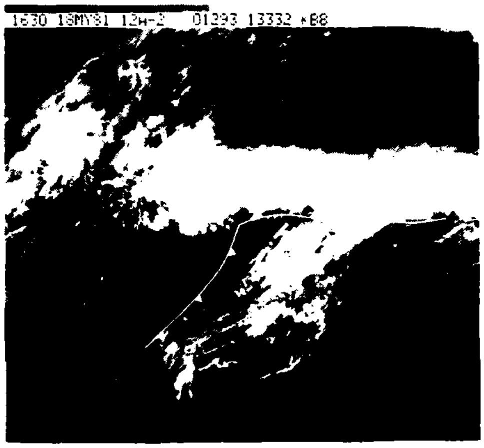


Figure 266: 1630Z 18 May 1981

Figure 267: 1830Z 18 May 1981

Further development occurs along the outflow boundaries (see outflow boundaries on next page) south of the departing squall line (A, Figure 26) and are also embedded in the nimbo-stratus north of the warm front (B, Figure 26). The new squall line which developed along the outflow boundary moved eastward into northern Mississippi the following day, and triggered new activity in western Tennessee (C, Figure 268 and C, Figure 269). As the squall line moves eastward away from the front, new convection develops back to the west along the dry line close to the front (D, Figure 268 and D, Figure 269). Thunderstorms in the nimbostratus region continue to persist (B, Figure 268 and B, Figure 269). With time, they tend to organize into a comma-shaped system apparently associated with the PVA maximum of the storm (B, Figure 269).

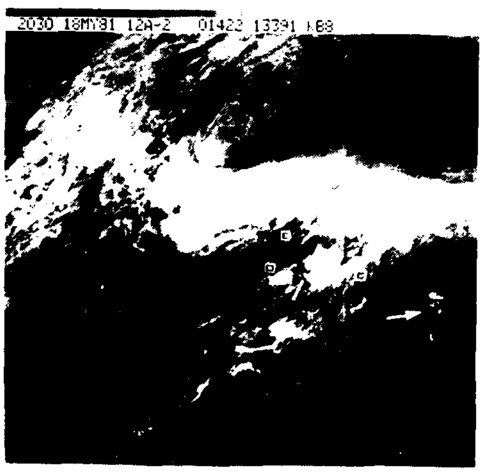


Figure 268: 2030Z 18 May 1981

Figure 269: 2230Z 18 May 1981

Outflow Boundaries (Arc Clouds):

Satellite pictures have proven that thunderstorms usually develop in areas which receive maximum solar insolation (cloud-free areas). As these storms dissipate, they produce an outflow boundary similar to a "mini" cold front (often called a gust front or arc clouds) as they dissipate. Figure 270 illustrates an outflow boundary across northern Mississippi and Alabama (see arrow). During the warm season, outflow boundaries can be seen on most visible satellite pictures such as shown at A, Figure 271. The circular dark areas within the cumulus streets are areas of drier, cooler air (downrush) located behind these outflow boundaries (B, Figure 271); the parent thunderstorm has dissipated and is no longer visible. In Figure 271, new convection is forming along the outflow boundary. In Figure 272, the dashed line indicates the leading edges of outflow boundaries noted in Figure 271. (Note: Many outflow boundaries appear much smaller than the boundary at A in Figure 271. Several small boundaries are noticeable in Alabama and Missouri in Figure 271.)

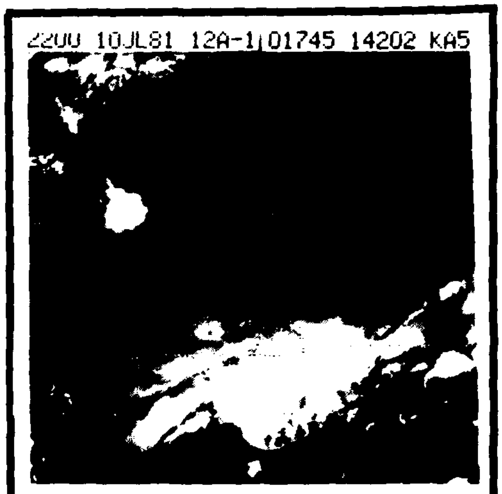


Figure 270: 2200Z 10 July 1981

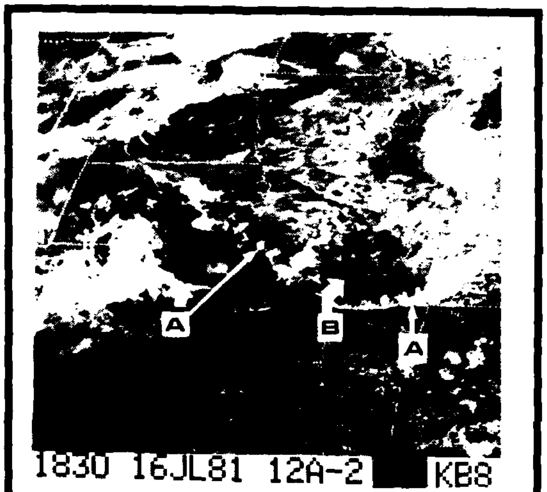


Figure 271: 1930Z 03 June 1981

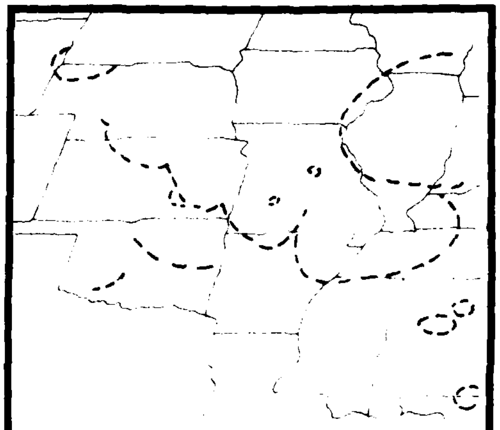


Figure 272: Outflow Boundaries

Intersecting Boundaries and Convection:

The outflow boundaries move away from the base of the parent cloud and interact with outflow boundaries from other such storms (Figure 273 a and b) or with existing boundaries such as fronts, sea breeze fronts, moisture ridges, etc...to cause new thunderstorm development (after Purdom, 1979)(4). The new storms are likely to be more severe than their parents due to the added energy of low-level convergence.

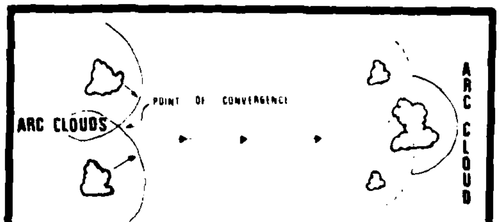


Figure 273a: Now | Figure 273b: Later
Figure 273: Intersecting Boundaries

Some of these outflow boundaries have long lives (some have been recognizable out to 8 to 10 hours) while others can be monitored for only two to three hours. The greater the intensity of the parent thunderstorm, the more obvious and long-lived the outflow boundary. Forecasters must be aware that cirrus will obscure their view of outflow boundaries on many occasions, but they <u>must not forget</u> that these boundaries still exist and should be considered in the short range forecast for the area. They must also remember that convective cloud development is especially dependent on the time of day so they must maintain continuity on features that are located in their area of interest using conventional data. Let's look at a case study.

• Case Study (Figures [illegible] through 27[illegible]) - Figure sequence [illegible] illustrates [illegible] of the things discussed above. Starting at 1401Z, Figure [illegible], the [illegible] shown as an area of intense convection over eastern Texas and Louisiana; there is [illegible] weather outside of this convective zone. From the previous day's photos and current data, we know that an old frontal boundary exists westward from this convective zone across north-central Texas. Also, the sea breeze front was well established on the satellite pictures on the previous day. In both cases, clouds are not evident because of the time of day.

In [illegible] well-defined [illegible] moving southward [illegible] not clearly defined [illegible], the first [illegible] frontal boundary [illegible] of the early stages of convective [illegible] section of the outflow [illegible] with the front is noted at [illegible]. The sea breeze front [illegible] developed, [illegible]. Therefore, you should consider thunderstorms — [illegible] severe (based on Skew-T [illegible]) — as the outflow boundary progresses southward in this region.

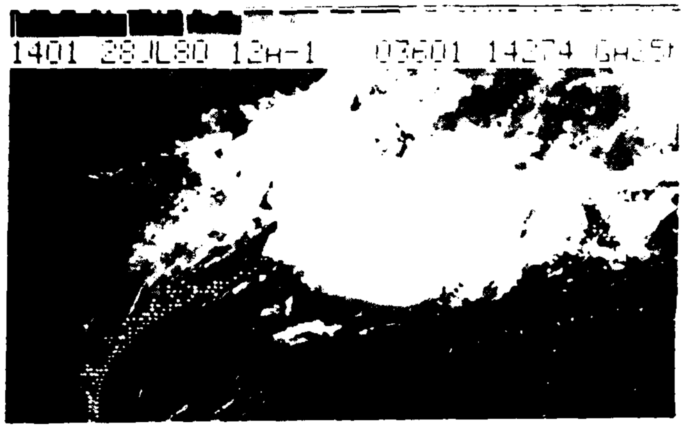


Figure 2-a: [illegible]

Figure 2-b at 1601Z begins to help cement the forecaster's thoughts. [illegible] vigorous along the old front (A) [illegible] becoming evident (see slightly lighter gray [illegible] (B)). The outflow boundary (D) is clearly evident [illegible] decaying parent thunderstorm region (E). [illegible] is the area of increased moisture over the Gulf [illegible] and it is now obvious that the outflow boundary is [illegible] type of activity in this area should be made.

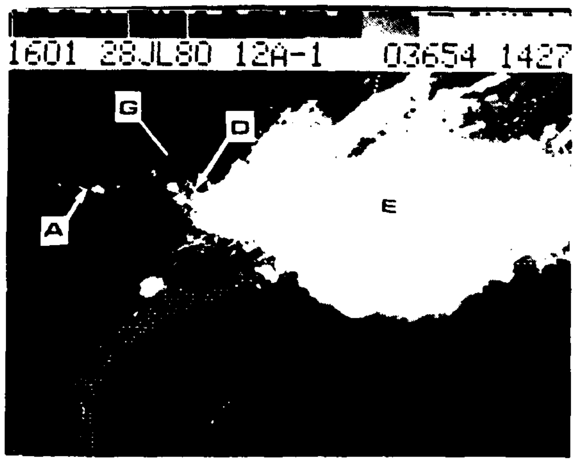


Figure 2-b: 1601Z [illegible] July 1980

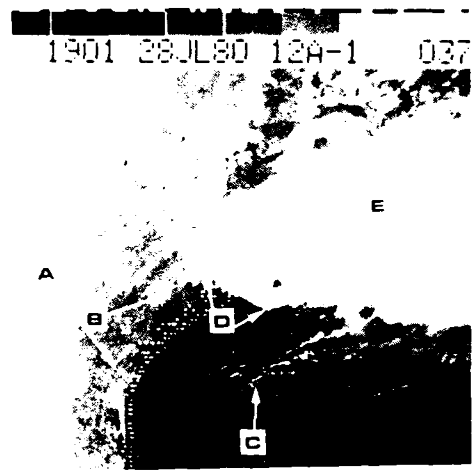


Figure 2-c: [illegible]

The final photo, Figure [illegible], confirms [illegible] thoughts. A severe thunderstorm has developed at the intersection of the sea breeze front and the outflow boundary (B). It is moving [illegible] the sea breeze front at the same speed [illegible] outflow boundary. The outflow boundary [illegible] triggered showers and probably thunderstorms over the Gulf as it intersected with the moisture ridge (C). There is a vigorous, perhaps severe, thunderstorm at the intersection of the old front and the outflow boundary (G). Finally, outflow boundaries from older storms along the front are enhancing cumulus buildups at their intersection points (F).

Again, there is no magic to severe weather analysis and forecasting as long as you know that it takes instability, moisture and a trigger. This case study clearly illustrates *that meteorological logic can be applied to the* clues obtained from the photographs to provide top quality weather warning and METWATCH service for convective activity.

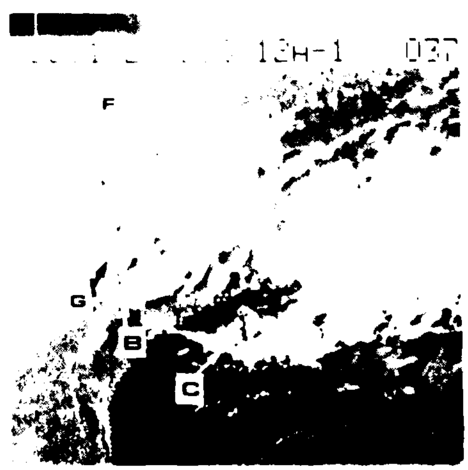


Figure 2-d: [illegible]

Organized Convection:

Most of the information we have discussed considers [illegible] frequently, thunderstorms will develop in lines associated with [illegible] photograph). These thunderstorms are most likely to be the real severe weather producers - perhaps even tornadic. The trigger is not always evident from [illegible] maybe not even on satellite data. Forecasters must observe the [illegible] of any organized convection.

An example is shown in Figure [illegible] (see arrow). In Figure [illegible] clouds exist throughout the central U.S. but appear to be enhanced [illegible] in eastern Missouri. Two hours later, a squall line has developed in western Illinois (see arrow, Figure 279). The point is: Forecasters should be wary of thunderstorms [illegible] develop along lines - the forecast you make may save lives.

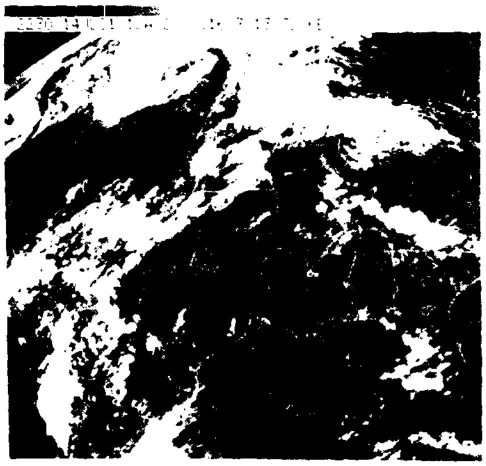


Figure 278: 2030Z 14 July 1981

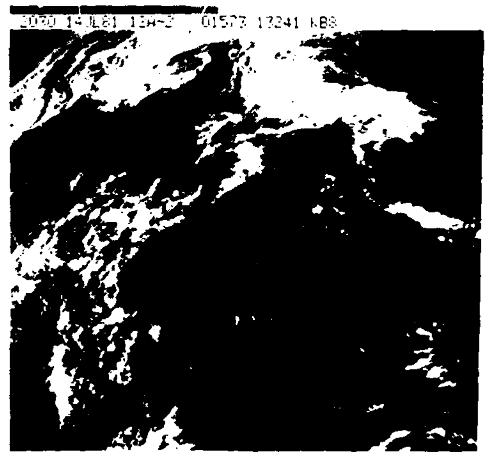


Figure 279: [illegible] 14 July 1981

Mesoscale Convective Complex (MCC):

Organized, persistent areas of deep convection are noted [illegible] satellite [illegible] the warm season, especially over the central areas of the U.S. [illegible] areas, referred to by Maddox (9) as mesoscale convective complexes (MCCs), [illegible].

Mesoscale convective complexes usually begin as a group of cells [illegible] unstable zone during the afternoon hours. The triggers, besides [illegible] low-level convergence zones, dry lines, fronts and the Rocky Mountains. Figures [illegible] a Rocky Mountain event. In Figure 280, many developing cells are noted [illegible] eastern Colorado and Wyoming.

The cells continue to grow and merge (while still going through [illegible] amounts of moisture are transported into the upper levels by these cells, [illegible] to produce an apparent single monster as noted by the arrow in Figure [illegible] (seven hours later than Figure 280). These systems continue to grow throughout the night [illegible] numerous thunderstorms and heavy precipitation over a given area. They [illegible] result of severe thunderstorms with tornadoes and hail, but this type of [illegible] persists once the nocturnal MCC has developed.

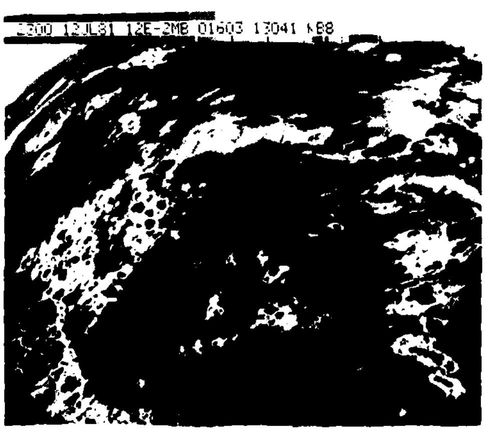
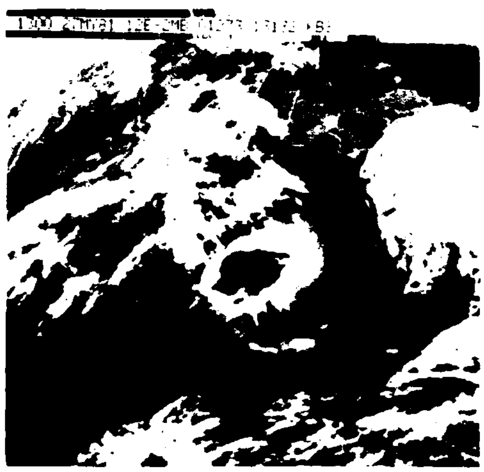


Figure 280: 2300Z 12 July 1981

Figure 281: [illegible] 13 July 1981

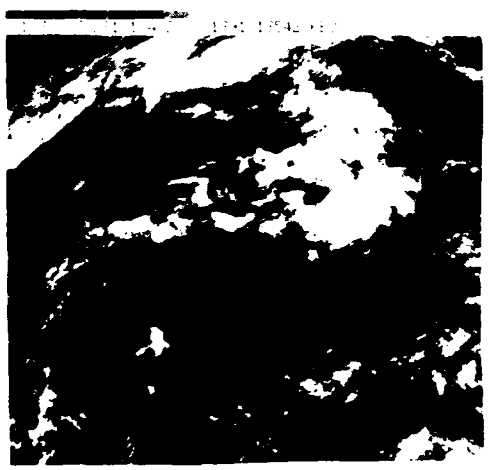
[illegible]



[illegible] May [illegible]

[illegible] August [illegible]

[illegible]



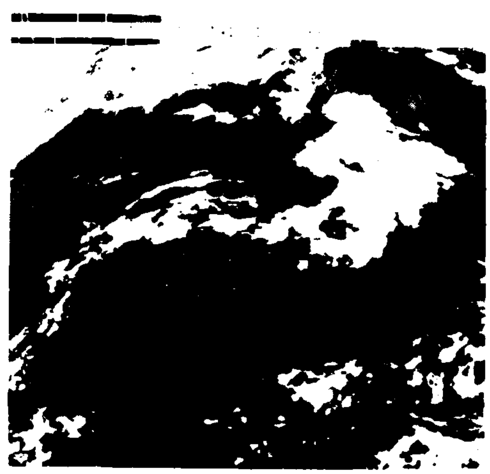


Figure [illegible] July [illegible]

Figure [illegible] July [illegible]

Locations lying in the path of [illegible] thunderstorm activity and heavy rainfall [illegible] pose a threat during [illegible] passage of [illegible] during late spring and continue through the [illegible] lighter during the summer (presence of the [illegible] slow movers.

Figure [illegible] February [illegible]

[illegible] May [illegible]

Figure [illegible]: 2300Z 14 May 1981

Figure [illegible] January [illegible]

In mature comma systems, the occlusion and the fast-moving portion of the cold front are easy to locate; they lie along the western end of the cloud system within the surge region as shown at F in Figure 290. The slower trailing portion of the cold front will be near the frontside of the cloud band as shown at G in Figure 290. Warm fronts are difficult to place across the comma head where a large area of cloudiness exists. Conventional data should be used to locate warm fronts.

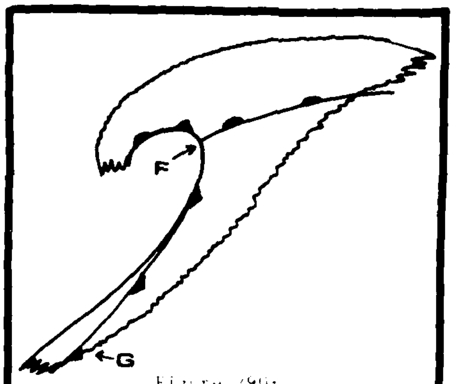


Figure 290: Example: Frontal Locations

Cutoff Lows:

Cutoff lows appear more often during the transitional periods of autumn and spring because the main belt of westerlies lies across the northern U.S. and Canada. In Figure 291, two cutoff low systems are shown across the southern U.S. Occasionally, short-wave trough systems moving through the westerlies extend far enough southward into the central and southern U.S. so that conditions favorable for a closed low circulation are established. Preceding and during the cutoff period, the main jet stream continues to lie to the north although a weaker jet may appear within the closed low circulation. Cutoff lows may occur over any area of the U.S. at any time of the year. They seem to favor the area over the southwestern U.S. and adjacent ocean areas. These systems often move slowly, and it is not uncommon for one to appear continuously on the upper air charts for a week or more. Cutoff lows sometimes appear as a result of blocking patterns and may remain nearly stationary for days until the block has broken down.

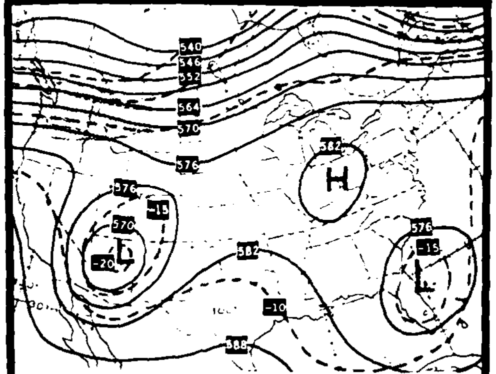


Figure 291: 1200Z 3 November 1976

The surface weather associated with these systems varies and is dependent upon the cutoff low's area of development. Heavy rains and flooding conditions may occur over the central and eastern U.S. for several days when a cutoff low moves into or develops over the south-central U.S. The surface system circulation is generally weak. Widespread fog formation is possible after passage of a cutoff low due to the weak pressure pattern, clearing skies, cooler temperature and a wet surface. Let's look at a case study.

• Case Study - The following cutoff low system affected the central U.S. for at least a week. Satellite and conventional data are included with this autumn event.

Figure 292 depicts the IR satellite photo approximately 12 hours before upper low development. A short wave vorticity system (X), located over the central Rockies, is moving towards a weak, stationary baroclinic zone cloud system (A) lying from Texas to the Great Lakes. The related 500mb Height/Vorticity initial analysis, Figure 293, reveals the Rocky Mountain vorticity system. The baroclinic zone (A) is weak - the vorticity isopleths barely cross the height contours across the central plains.

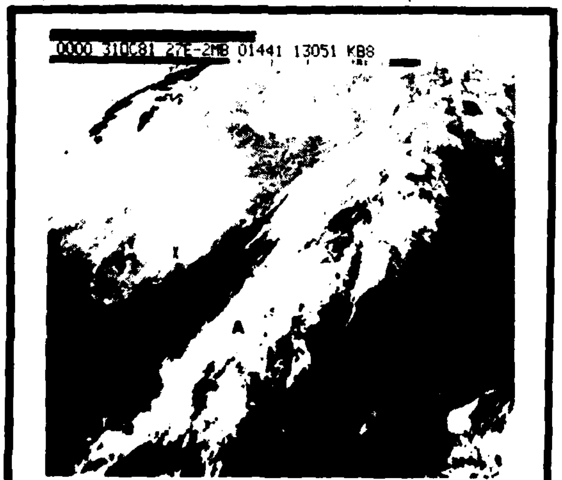


Figure 292: 0000Z 31 October 1981

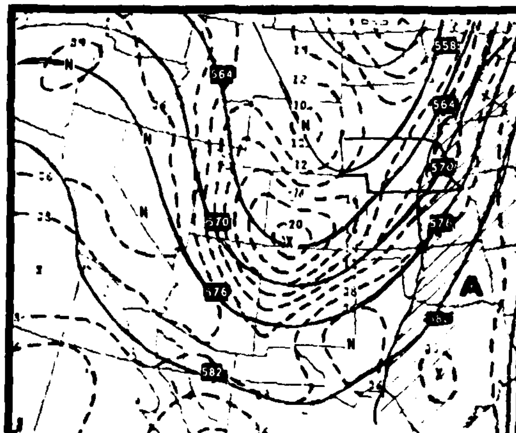


Figure 293: Initial 500MB Heights/Vorticity 0000Z 31 October 1981

[illegible] Southern New Mexico northward into the [illegible] of New Mexico and Texas [illegible] of the year are other considerations for [illegible] low development.

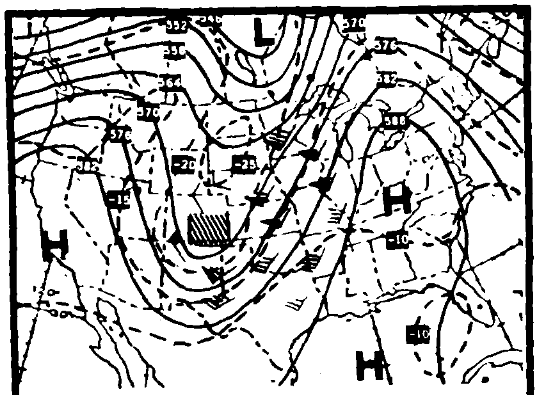


Figure 294: [illegible] 31 October 1981

Approximately three hours later, [illegible]

Figure 295: 1430Z 31 October 1981

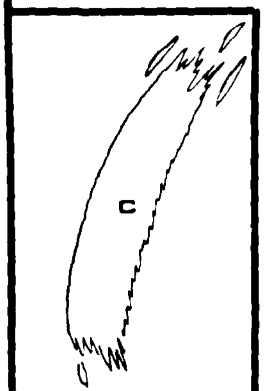


Figure 296: [illegible]

In the IR photo eight hours later, Figure 297, the deformation zone [illegible] system [illegible] has expanded across the Great Plains suggesting that an upper level low has formed. The tops of the [illegible] clouds have built as noted by the gray shades.

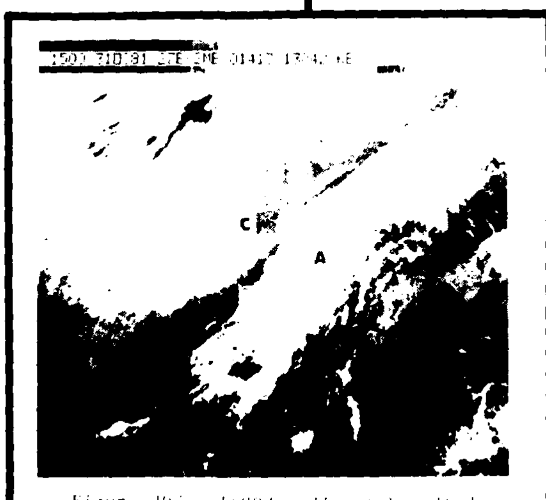


Figure 297: 1500Z 31 October 1981

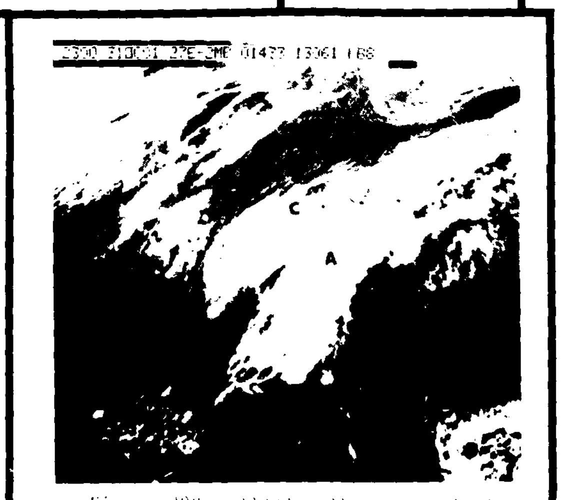


Figure 298: 2300Z 31 October 1981

The following morning, Figure 299, the deformation zone cloud borders have become better defined and reveal cyclonic circulation. The related 500mb analysis, Figure 300, shows a cutoff low system over the southern Great Plains - a blocking high/cutoff low pattern has evolved - a pattern typical during autumn. Figure 301 depicts the surface pattern - low ceiling and steady rain are noted across the central Great Plains. The visible photo, several hours later, Figure 302, shows a mature cutoff low system. Forty-eight hours later, Figure 303, the system still appears over the same general area but shows signs of dissipation. The low shifted slowly eastward during the next several days and continued to weaken.

Mature cutoff lows often become barotropic (Figure 304) and begin to dissipate. Locations affected by these stagnant systems may experience the same weather conditions for several days in a row. Attempting to forecast the overall movement of cutoff systems is a challenge.

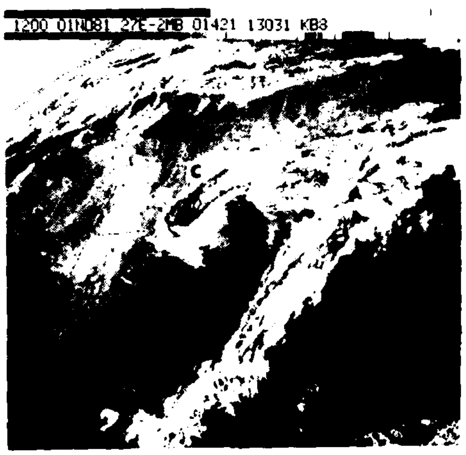


Figure 299: 1200Z 1 November 1981

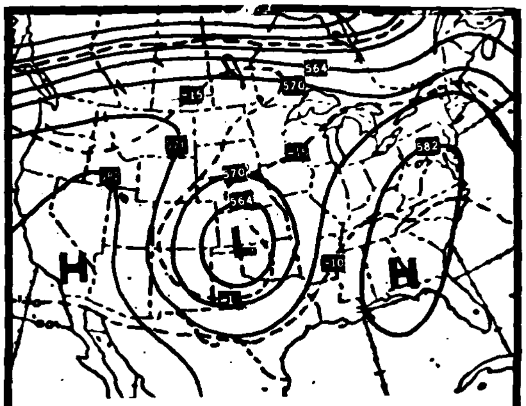


Figure 300: 500MB 1200Z 1 November 1981

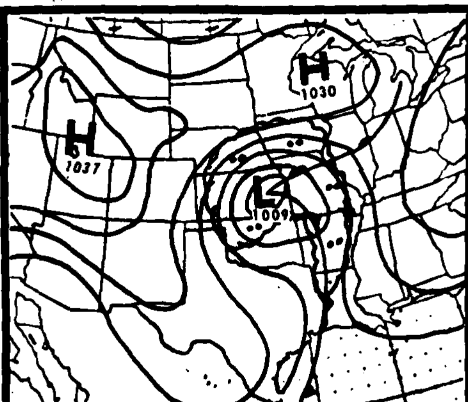


Figure 301:
Surface 1200Z 1 November 1981

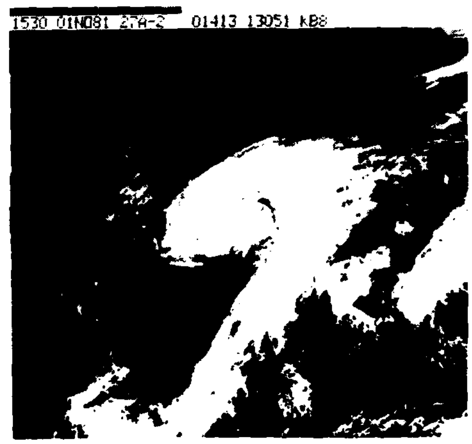


Figure 302: 1530Z 1 November 1981

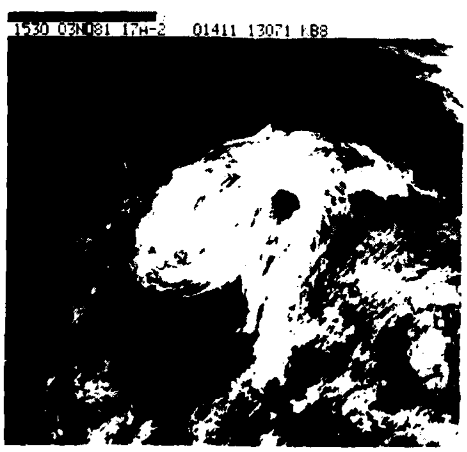


Figure 303: 1530Z 3 November 1981

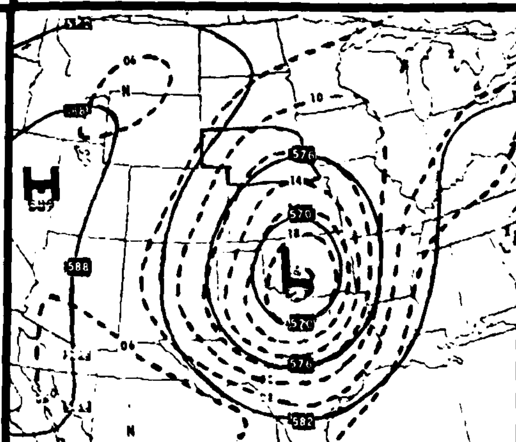


Figure 304: LFM 24HR Forecast
0000Z 2 November 1981

Tropical Storms:

Tropical storms appear on the satellite scene during the warm season usually by late summer. They may, however, appear as early as May. Tropical storm events generally end by late October or early November.

• Western U.S. - Tropical storms are frequently found on satellite photos south of Baja, California such as shown in Figure 305. They form off the west coast of Mexico and Central America. System movement is generally towards the west or northwest dissipating as they move across the vast expanse of the eastern Pacific. Occasionally, however, tropical storms will drift northward or northwestward to affect Baja, California, Mexico and the southwest U.S. (more likely to drift northward during August and September as the subtropical ridge, located over land, weakens and shifts southward). Consequently, increased moisture and instability associated with these systems produces heavy thunderstorms and flash floods over the desert southwest. The effects of these systems may even be felt over the southern Rockies eastward into the Great Plains; the associated cloud systems can be easily tracked on satellite photos.

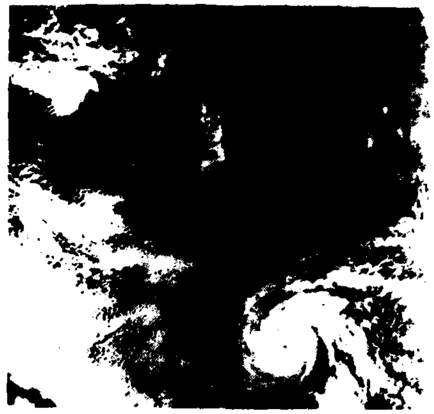


Figure 305:
Tropical Storm South of Baja, California

• Eastern U.S./Gulf Coast - Early warning is generally provided to U.S. interests when tropical storms form within the ITCZ across the central Atlantic eastward to the African coast. On the other hand, coastal forecasters may be surprised by the quick development of a disturbance over the warm waters of the Atlantic Ocean, Caribbean Sea and Gulf of Mexico (Figures 306 and 307, respectively visible and IR photos).

Figure 306: 2000Z 16 August 1981
(T. S. Dennis)

Figure 307: 0947Z 17 August 1981

An example of a Gulf of Mexico event is now shown:

• Example - Forecasters should suspect all disorganized, deep convective cloud systems which appear offshore such as shown across the eastern Gulf of Mexico in Figure 308 (the cloud system shown in Figure 308 is often designated an easterly wave). These systems may be upgraded from a tropical depression to a tropical storm, or perhaps, a hurricane within a short time.

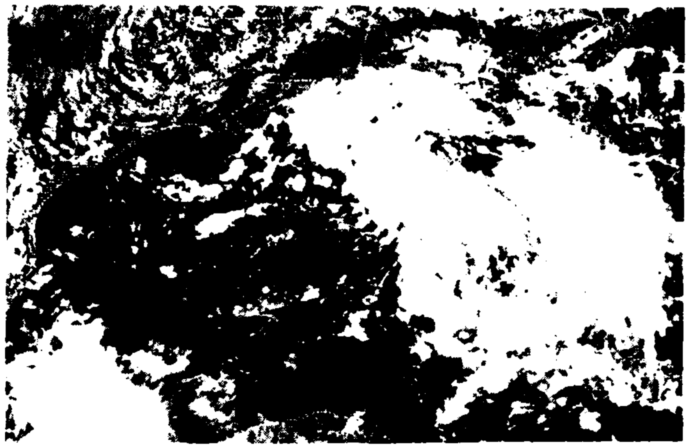


Figure 308: 1930Z 3 September 1980

In Figure 309, [illegible] hours later, some organization is noted within the [illegible] system, and it appeared on surface charts as a weak low system. Fortunately, this system [illegible] a tropical depression as it moves slowly towards Texas.

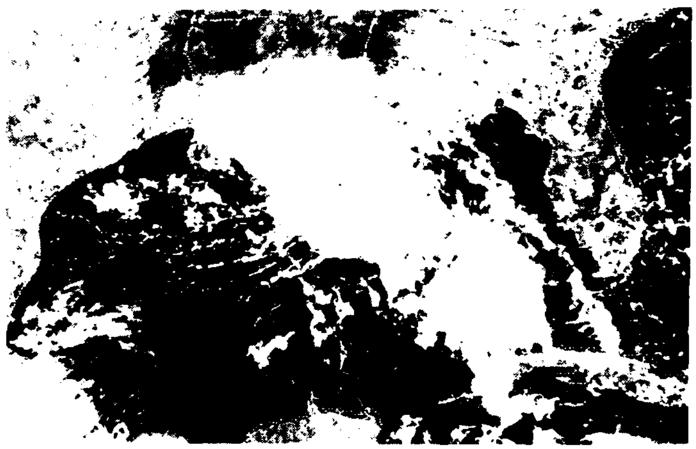


Figure 309: 1730Z 4 September 1980

Weak tropical storms such as shown in the example in Figures 308 and 309 may still be dangerous to inland locations lying within it's path. The associated moisture and instability spread inland (combined with heating and rising terrain), and trigger thunderstorms, tornadoes and heavy rainfall over a large region (Figure 310). The remnants of a hurricane can spread havoc far into the interior over a period of several days.

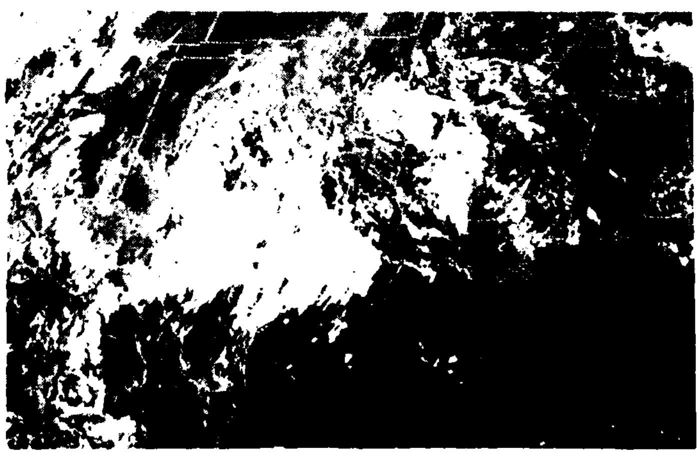


Figure 310: 1930Z 8 September 1980 (4 Days Later)

PART III

PATTERNS OF CYCLOGENESIS

This part is designed to illustrate basic comma cloud cyclone development patterns as seen in satellite pictures. The information that follows was extracted from the NWS satellite training course notes (1975; unpublished) by Mr. Roger Weldon.

Part III will begin by showing two primary winter cyclone patterns. Then, several models of cyclone development will be discussed.

SECTION 1: Cloud Patterns Associated with Mature Winter Storms:

Major cyclones, especially the large winter storms of the westerlies, often have complex cloud and weather patterns associated with them. Each cyclone's cloud pattern is different and *each storm is made up of the sum of its parts.* Some storms begin with one short wave disturbance and develop into a large mature storm pattern before any additional short waves enter the circulation pattern. Most mature winter storms, however, contain one or more short wave disturbances in addition to the primary one which was involved in the initial cyclogenesis. In fact, *it is very common to have two or three short wave disturbances at any given time within* the circulation system of a large winter storm. It is the presence of these smaller scale systems which contribute largely to the variability in the cloud and weather patterns of the storms. This is the reason for the earlier statement that a storm is made up of the sum of its parts.

Major Cloud Systems:

In the models that will be presented, three major cloud subsystems are observed during various phases of system development. These systems were defined and shown in many illustrations in Part II. Again, the cloud systems are:

- Baroclinic Zone Cirrus (A)
- Vorticity Comma (B)
- Deformation Zone Cirrus (C)

Cloud Structure of Mature Storms (Figures 311 and 312):

The cloud structures or patterns during the mature stage of cyclones differ less than during their developmental phases. Two typical cloud patterns observed during the mature stages are identified as: Type A and Type B. The cloud patterns in both types are intended to represent storms which have just reached their lowest central pressure.

- Type A (Figure 311) - Type A systems initially develop within the lower levels and subsequently appear within the mid and upper tropospheric level as the cyclone matures. With the Type A systems, there is a large expanse of baroclinic zone cirrus just east of the comma surge region (area A in Figure 311). This cirrus shield often masks part of the comma surge region and comma tail which only reach up to mid-levels (area B). There is only a small amount of deformation cirrus near the comma head (area C). There is a distinct separation between the baroclinic zone cirrostratus and deformation cirrus layers. A Type A system has a well defined jet axis and lies close to the edge of the baroclinic zone cirrus deck as shown in Figure 311 (see Figure 148, page 37).

The cold and occluded fronts are usually easy to locate in Type A systems as illustrated in Figure 311. Warm *fronts locations are difficult to find,* especially if the cirrus shield is too thick to see through. This is true in both Type A and Type B (Figure 312) systems. If the clouds are too thick to see through, a first guess at the warm frontal location is that it would be below the widest point on the baroclinic cirrus shield.

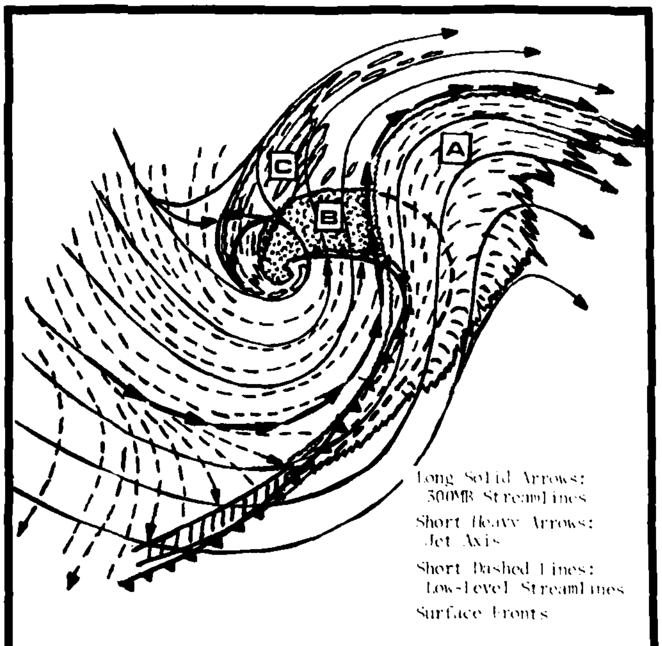


Figure 311: Type A Mature Storm

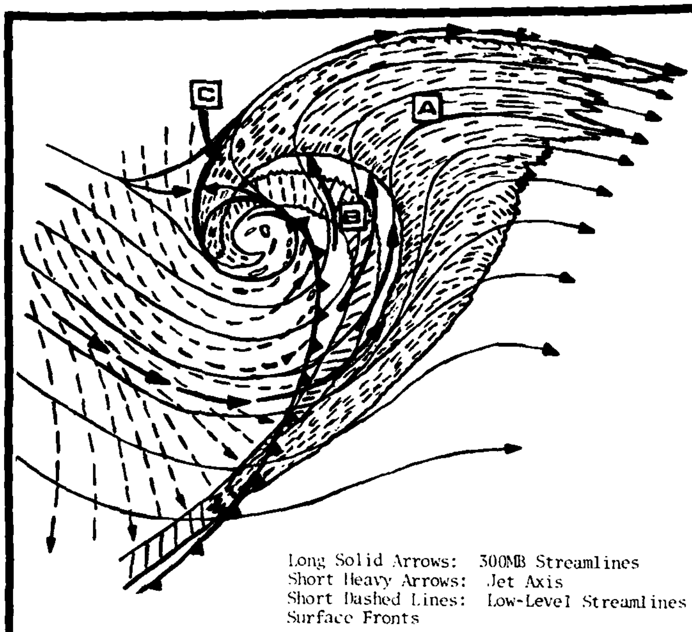


Figure 312: Type B Mature Storm

• Type B (Figure 312) - Type B systems initially develop within the mid levels and builds both upward and downward. The Type B system's baroclinic zone cirrus (area A in Figure 312) merges with the large sheet of thick deformation cirrus (C). The baroclinic cirrus shield tends to move faster than the middle level comma (B); thus the comma emerges from under the rear edge of cirrus with time (see Figure 146, page 36). There will be a four to six hour clearing of mid and upper clouds between the baroclinic zone cirrus shield and the vorticity comma. Units located within this gap or slot in the higher clouds (low clouds may cover the gap) should look for a return of precipitation and embedded convection as the vorticity comma approaches. The jet stream in a Type B system is often ill-defined due to its spreading out under the baroclinic cirrus shield. This spreading of the jet stream is noted by the three larger arrows near B in Figure 312. The baroclinic leaf usually evolves into the stronger Type B systems.

Type B's are usually deep, well-developed systems with all types of severe weather under the comma in its mature stage. During fall and winter, the convection within the comma can cause heavy precipitation; during spring, severe thunderstorms may occur. Even more convective precipitation may break out along the cold front. Both Type A and Type B will produce heavy snows, however, Type B systems produce the heaviest blizzards. Type B systems have the potential to be a stronger, better developed system than the Type A system. A Type A system may evolve into a Type B system once its vertical support reaches mid levels.

Fronts on the Type B system are usually complex, and large areas of cirrus make it more difficult to locate frontal systems. The baroclinic zone cirrus shield and vorticity comma and their associated clouds and precipitation may outrun the surface cold frontal system as depicted in Figure 312.

Models of Cyclogenesis:

The models of cyclogenesis which will be presented in Section Four are systems whose cloud patterns evolve to one of the two mature stages illustrated in Figures 311 and 312. Many more systems begin to develop, but they do not make it to the mature stage. As an example, many short wave systems develop and intensify within a zonal flow pattern. They continue to maintain their short wave structure as they track across the U.S.

Three primary models of cyclogenesis, meridional, split flow and cold air regime, will be presented respectively in Sections Two through Four; Section Four will contain two types of cold air cyclogenesis: cold air vortex and induced wave type.

Meridional trough cyclogenesis is most prevalent along the east coast of North America and over the adjacent western Atlantic. This type occurs also over parts of the U.S. and over the oceans as well. The sequence of cloud development in meridional trough cyclogenesis is:

- Baroclinic Zone Cirrus (A)
- Vorticity Comma Cloud (B)
- Deformation Zone Cirrus (C)

Upper Air Flow Patterns (Figure 313):

The upper air support for the initial stage of this type of cyclogenesis is a trough that has a large meridional extent. Two examples are shown in Figures 313a and 313b. In Figure 313a, the trough axis is aligned north-south, whereas in Figure 313b, the axis is oriented northeast-southwest (positive tilt). The jet axis is located around the trough - without any significant jet branches extending either across the trough or outward into the adjacent ridges. Short wave disturbances including the one initiating the cyclogenesis, move around the major trough within or under the jet baroclinic zone. These disturbances or impulses are difficult to locate in the curvature of the contour and thermal fields of the large-scale trough; they usually show best as maxima or perturbations in the 500mb vorticity field, or as speed maxima moving within the jet zone.

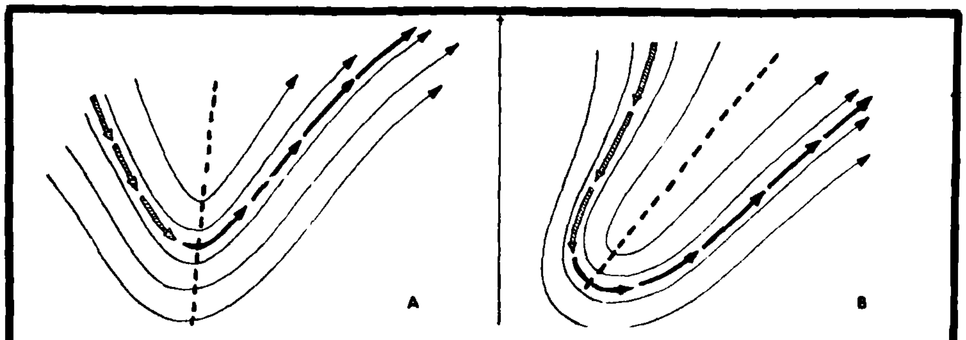


Figure 313: Two Sample Flow Patterns for Meridional Trough Cyclogenesis

Note: In Figures 313a and 313b, and in all subsequent upper flow pattern illustrations, the jet stream directly associated with cyclogenesis is shown as cross-hatched. The main (older) jet is indicated by the solid arrows.

Early Stage - Phase 1 (Figure 314):

The cloud pattern at the beginning of the cyclogenetic process shows a large band of baroclinic zone cirrus to the south of a relatively strong jet stream (area A in Figure 314). Below the baroclinic zone, there is a relatively stationary or very slow moving cold frontal system. All along this front there are small ill-defined low pressure waves as shown in Figure 314. Each wave has its own small comma cloud and precipitation; the small commas are generally hidden below the large area of baroclinic zone cirrus and cirrostratus. When meridional trough cyclogenesis does begin, it will be in response to one of the small or short wave scale vorticity maxima as they come around to the front side of the main trough. The problem is: which one, and can it be seen coming either in the satellite or other conventional data. Usually they move rapidly down the backside of the major trough and are often difficult to pinpoint within the upper air network. Additionally, there are few clouds associated with the minor disturbance when it is moving southward behind the trough. (Sometimes, an area of thin cirrus streaks on the backside of the trough may be seen; this indicates the position of the major short wave.) The clouds form when the disturbance reaches the east side of the major trough (recurvature), and then it is likely under the baroclinic zone cirrostratus layer. The only real key to catching the development is to wait until it begins and catch it immediately. The first real hint of development is a significant waving of the back edge of the cirrus shield - this is Phase 2.

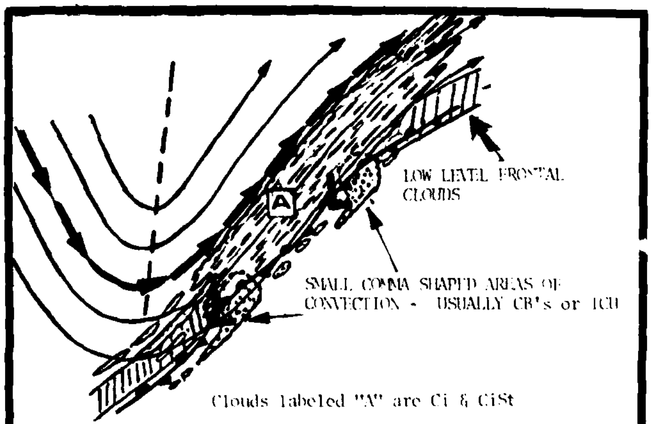


Figure 314:
Early Phase in Meridional Trough Cyclogenesis

Phase 2 (Figure 315):

In the second phase, the cirrus edge has formed a wave pattern which is also matched by the jet axis and streamlines (Figure 315). This waving of clouds and the flow indicates that a short wave trough either has formed or has bottomed out within the major trough. In Figure 315, the dashed line is a comma-shaped area (B), it would not be visible on satellite data, since it is under the baroclinic cirrostratus deck (A). It corresponds to the location of the vorticity comma which has now formed in the process of cyclogenesis. The short wave's influence within the base of the major trough has caused the trough axis to become negatively-tilted. Aside from any thunderstorm development, area B is likely to be the area of heaviest precipitation. At this stage, the frontal system shows strong waving; the associated frontal low begins to deepen.

Phase 3 (Figure 316):

In the third phase of development, the system begins to "wrap up" and form a closed circulation center into the middle troposphere. The lower level comma head begins to emerge from under the cirrus deck (area B in Figure 316). The comma head, although emerging, is not likely moving westward (or rearward) with respect to the ground; rather the cirrus edge is moving faster. The short wave trough has lifted so much and has increased in size; the entire base of the major trough now has a negative tilt. By this time, the system is closed up to 700mb but not up to 500mb. The short wave ridge has increased its amplitude.

The surface cold front is under the cirrus near the back edge of the comma pattern, and the surface low is now nearer to the back edge of the cirrus deck (the low was near the eastern edge at the initial phase). The storm is developing very rapidly at this time.

Significant precipitation will be falling throughout the comma head. Although the cloud tops in the comma head are normally middle level, they do often reach cirrus levels but lower than the cirrus deck to the right of the jet axis.

Phase 4 - Mature Stage (Figure 317):

In the final phase of development, the closed circulation has deepened even more; an area of deformation cirrus (area C) has formed, and the overall pattern fits the Type A cyclone shown earlier in Figure 311. The dry slot has wrapped itself into the comma head. The jet in this type of cyclogenesis is still relatively strong while crossing the comma. The jet and its baroclinic zone cirrus shield will be well to the east and separated from the deformation cirrus. By this time, the low should be closed up to at least 500mb. There is a trend for the surface and upper centers to rotate cyclonically with respect to each other, getting closer together, until the systems are vertically stacked.

The surface low is well west of the cirrostratus deck and north of the mid and upper level low centers. Remember, this is a Type A system, and as such, it will fill as it was built - from the bottom.

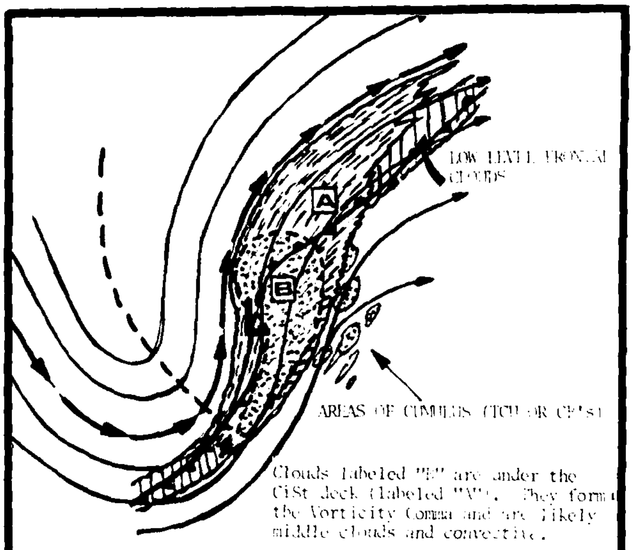


Figure 315:
Second Phase in Meridional Trough Cyclogenesis

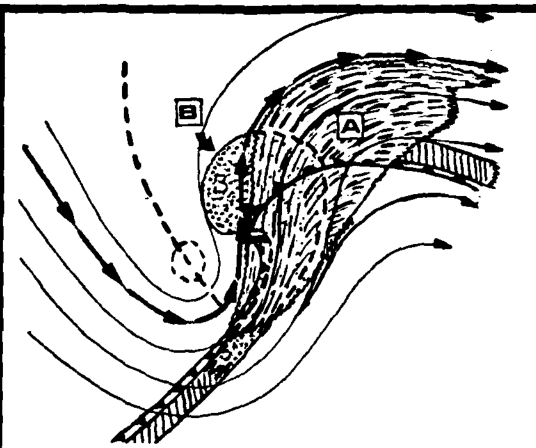


Figure 316:
Third Phase in Meridional Trough Cyclogenesis

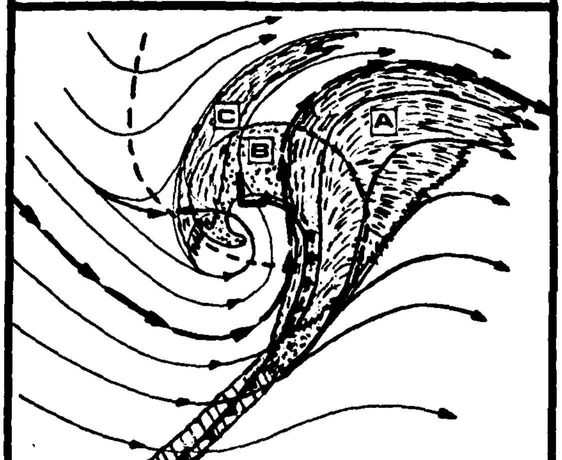


Figure 317:
Fourth Phase in Meridional Trough Cyclogenesis

SECTION 3: Split Flow Cyclogenesis

Split flow cyclogenesis is the most prevalent form of cyclogenesis over the central U.S. just east of the Rocky Mountains. The split flow pattern is most often induced by a major mountain chain. Split flow patterns occur frequently, such as on the west side of the common blocking patterns, but the development of cyclogenesis also requires a jet moving into the southern branch. Thus, split flow cyclogenesis is much less common than split flow. Split flow cyclogenesis develops in the mid levels, and as such, it develops directly into a Type B cloud system (see Figure 312). The sequence of cloud development in split flow cyclogenesis is:

- Deformation Zone Cirrus (C)
- Vorticity Comma (B)
- Baroclinic Zone Cirrus (A)

Upper Air Flow Patterns (Figure 318):

The upper level flow splits or is diffluent. Often there are two branches of the westerlies forming, with the northern one being the older one. The new branch then forms further southward and may induce cyclogenesis as shown in Figure 318a. Or, there may be two branches throughout the period, with the main energy transferring to the southern branch during cyclogenesis (Figure 318b). In either case, the development occurs south of and on the warm air side of the older northern jet baroclinic zone.

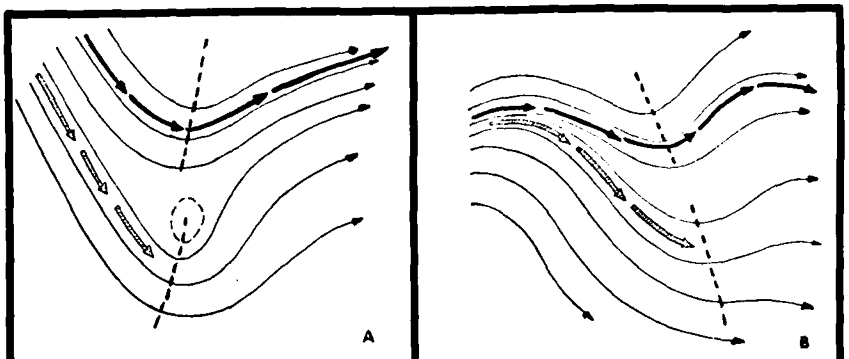


Figure 318: Two Sample Flow Patterns for Split Flow Cyclogenesis

Phase 1 (Figure 319):

In the beginning of split flow cyclogenesis, the jet stream enters the southern trough region on the western side of the troughline (Figure 319). Generally, a closed circulation center in the middle troposphere (500mb) appears early in the development. If the southern short wave is already closed as shown in Figure 319, then it will dig and deepen as the jet approaches the troughline. The early development of this mid-level low is probably the most important single factor that influences the evolution of cloud and weather patterns.

The cloud pattern usually begins with an area of cirrus (and perhaps middle clouds) and is indicated as area C in Figure 319. This is deformation zone cirrus. Deformation zone cirrus exists where there is convergence on the east side of the out-of-phase troughline. The cirrus lies generally north and northwest of where the cyclogenesis is about to take place (if it hasn't already occurred). Deformation cirrus develops within a region of weak upper level winds located south of the northern branch of the polar jet and northwest of the developing mid-level low.

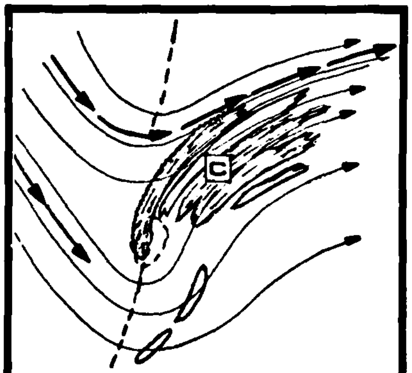


Figure 319: Early Phase in Split Flow Cyclogenesis

Note: In Phase 1 and the subsequent three phases of cloud evolution, the cloud systems identified are at the mid and high tropospheric levels. Great Plains forecasters must consider the advection (often rapid advection) of lower level Gulf moisture into these split flow patterns approaching the Rocky Mountains. With the introduction of Gulf moisture, the cloud evolution of the system may change dramatically within a very short time.

Phase 2 (Figure 320):

In the second phase of cyclogenesis, the most important change in the cloud pattern has been the development of the vorticity comma pattern which has formed very rapidly to the southeast of the closed low (area B in Figure 320). The cloud type in this early comma is highly dependent upon the time of day and the season of the year. In the springtime, this comma is highly convective during the day, but still primarily of middle cloud height tops. Deformation zone cirrus continues to increase as the col area develops.

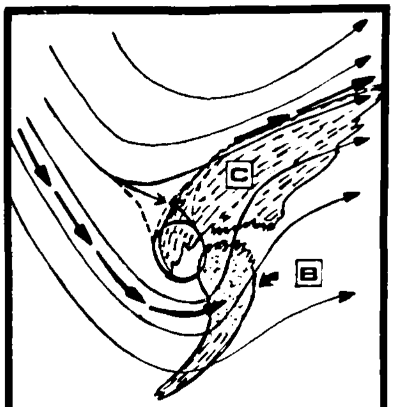


Figure 320:

Second Phase

in Split Flow Cyclogenesis

Phase 3 (Figure 321):

By phase three, the cloud patterns have become bigger and better defined. The comma pattern is topped by cirroform clouds. Over the comma tail portion, the cirrus will appear thicker and striated, as the jet baroclinic zone develops aloft over that area (this is the third cloud system: this area is noted by the large arrow in Figure 321). At this stage of development, Gulf moisture has spread into the system and is being lifted rapidly into the middle levels. As a result of this lifting, a large area of PVA (and precipitation) develops ahead of the disturbance across the Great Plains.

The jet stream has advanced south of the closed center and the jet maxima swings east of the troughline: these actions causes continued trough deepening, and most important, probable system recurvature towards the northeast (bottomed out).

No surface low or surface fronts have been included in Figures 319 through 321. The reason for this omission is the large variability involved in the relation between these surface features and the cloud patterns for this type of cyclogenesis. There is a good relationship between the cloud patterns and the weather (precipitation), but a much poorer relationship between the cloud patterns and the surface pressure and temperature fields. A generalized rule for placing the surface low center would be the following: the surface low will usually appear at a location somewhere near the rear edge of the comma head shown in Figures 320 and 321, and on the cyclonic side of where the jet is shown crossing the comma's rear edge.

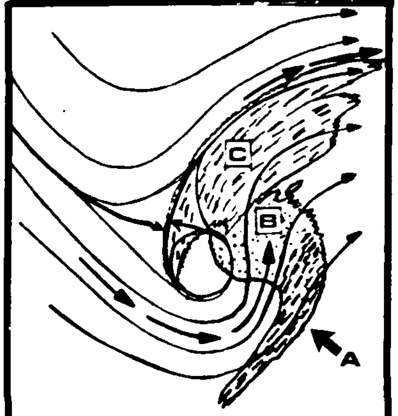


Figure 321:

Third Phase

in Split Flow Cyclogenesis

Phase 4 (Figure 322):

In phase four the jet wind maxima spreads out behind the baroclinic cirrus edge which produces light winds in the cloud shield itself. The entire system is evolving into a Type B mature storm pattern (see Figure 312). The short wave trough has become in phase with the northern short wave and may become negative tilted. (Negative-tilted troughs are often very dynamic and produce the most severe weather conditions.)

By this phase, the area of thick cirrus has greatly increased. Cirrus has formed over the vorticity comma and has merged with the northern, older area of cirrus (shown in Figures 319 through 321). By this time, it is often difficult to distinguish between the cirrus deck associated with the jet baroclinic zone (area A is Figure 322) and the deformation zone cirrus (C) to the north and rear of the closed low aloft.

Usually the cirrus deck that develops over the comma pattern is not contiguous with the lower middle layers. Quite often, then, the rear edge of the cirrus deck moves faster than the middle (or lower) deck which emerges at the rear. If the cirrus continues to outrun the comma cloud then a gap (possible clearing) between these two systems evolves and eventually becomes similar to the Type B storm pattern shown in Figure 312.

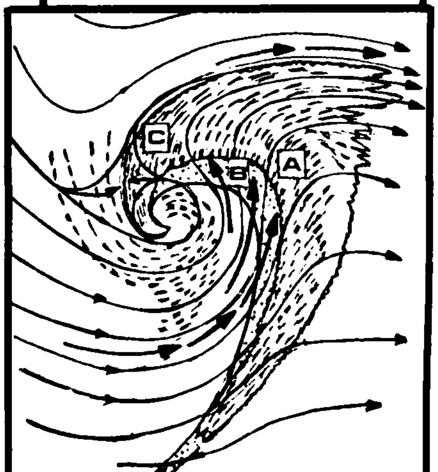


Figure 322:

Fourth Phase

in Split Flow Cyclogenesis

Many major snowstorms and severe weather occurrences across the Rocky Mountains and Great Plains are associated with split flow cyclogenesis events over the southwestern U.S. Forecasters may find it difficult at times to identify deformation zone and vorticity comma cloud systems which are associated with these developing upper lows over the western U.S. Sometimes mountain influences tend to dry out accompanying Pacific moisture which will produce ill-defined deformation zone and vorticity comma cloud systems. The cloud systems become better defined when the cyclone moves out of the Rockies and frequently encounters Gulf moisture advection. Let's look at a case study:

Split Flow Cyclogenesis - A Case Study (Figures 323 through 327):

Figures 323 and 324 respectively depict the 500mb and surface analyses approximately 24 hours prior to Great Plains storm development.

In Figure 323, a low system is shown over northwestern New Mexico. At the surface, a cold frontal system is becoming stationary across the western Great Plains.

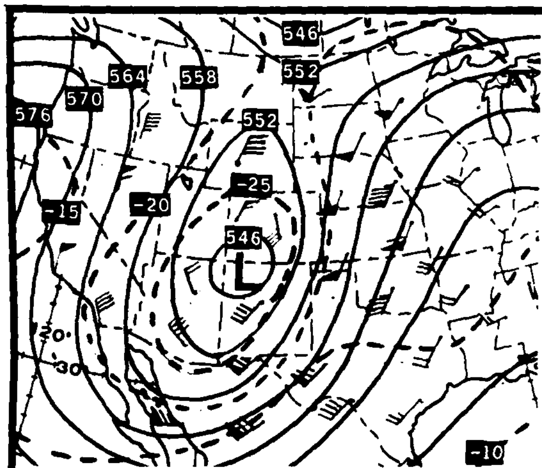


Figure 323: 500MB 1200Z 28 March 1981

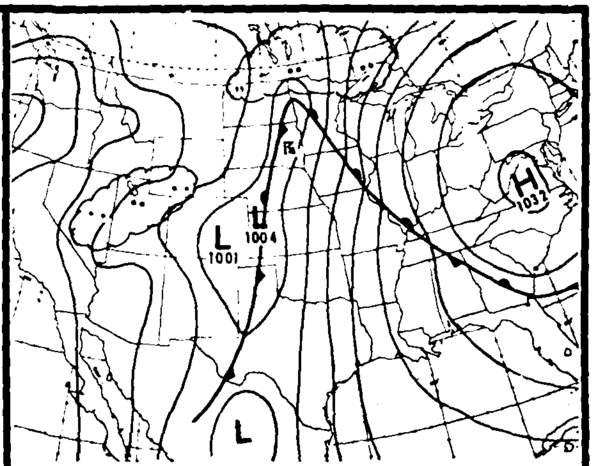


Figure 324: Surface 1200Z 28 March 1981

The IR photo, Figure 325 (three hours later), depicts a disorganized pattern of cloud systems across the central U.S. Deformation zone clouds are noted at C; an ill-defined vorticity comma system is shown at B. A PVA area (P), reflected by the highest cloud tops, lies to the right of the polar jet (and along the frontal zone) across western Kansas and Nebraska. Cirrus layers (S) associated with the subtropical jet are noted across Texas and the lower Mississippi Valley.

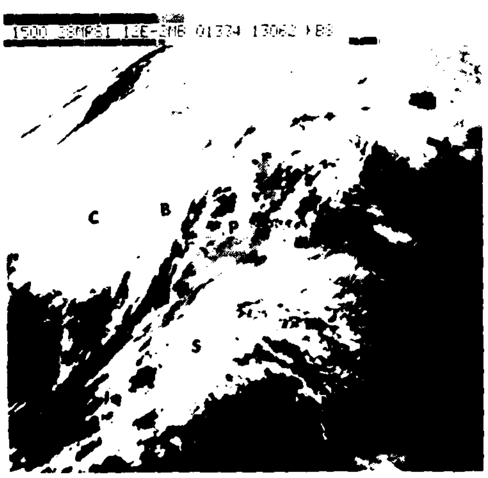


Figure 325: 1500Z 28 March 1981

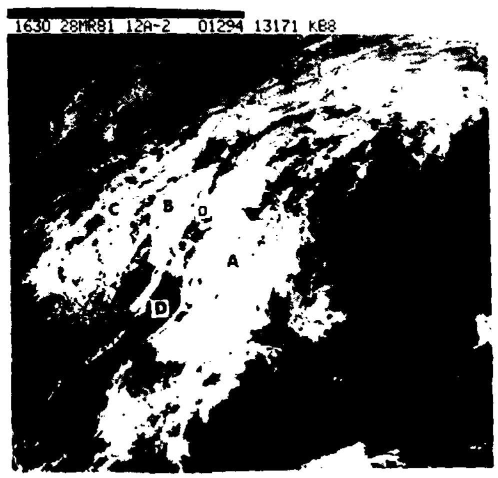


Figure 326: 1630Z 28 March 1981

AD-A111 956 WEATHER WING (3RD) OFFUTT AFB NE F/G 4/2
SATELLITE INTERPRETATION.(U)
DEC 81 E M WEBER, S WILDEROTTER
UNCLASSIFIED 3WW/TN-81-001 NL

2 OF 2
AD A
956

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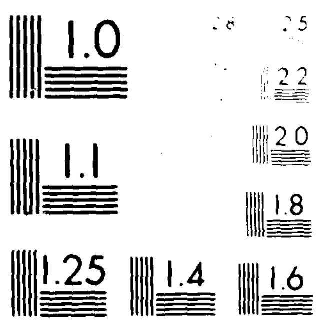
1.0
2.5
2.2
2.0
1.1
1.8
1.25
1.4
1.6

One hour and thirty minutes later, the related visible picture, Figure 327, reveals the deformation zone (C) and vorticity comma cloud (B) systems. Another cloud system, noted as A, appears across the Great Plains in the visible photo (faintly visible in the IR): this cloud system is Gulf moisture advection, and it has produced its own lower level baroclinic zone cloud system. The moisture tongue will continue, and with increased PVA associated with the approaching upper system, precipitation will break out over the Great Plains.

The area noted at D in Figure 326 marks the western extremity of Gulf moisture; it often becomes the developing cyclone's dry slot as drier, southwest winds move northeastward into the system.

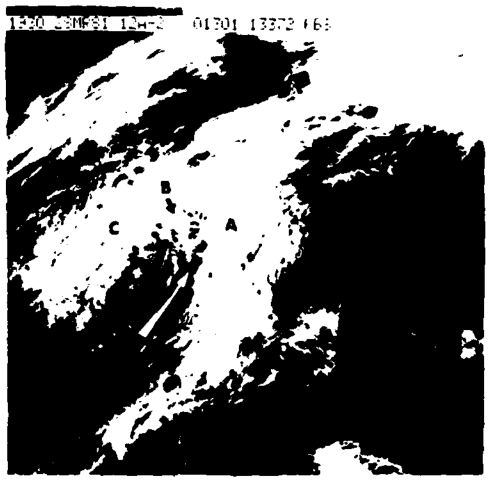

Figure 327: 1930Z 28 March 1981

Three hours later, Figure 328, the visible photo reveals system organization as the upper low moves toward eastern Colorado. The vorticity comma cloud's head lies over central and eastern Colorado (B); the comma tail extends southeastward into western Kansas. The growing dry slot is indicated by the long white arrow.

Figure 328: 2230Z 28 March 1981

Several hours later, Figure 329, the visible photo shows strong cloud circulation within the storm as it emerges from the central Rockies. The small arrows denote several small enhanced cumulus comma cloud systems rotating through the large scale system within the dry slot. Dust can be seen as the faint gray swath across west Texas.

In the previous two patterns shown, the influence of the North American continent (coastal and mountains) frequently induce the flow patterns for meridional and split flow developments. According to Weldon's studies, the third type of cyclogenesis, cold air regime development, was the most frequent type observed across North America and the north Pacific and Atlantic oceans. The cold air regime forms of cyclogenesis were most prevalent over the oceans, however, the geographical preferences for this type is not as strong as for meridional and split flow cyclogenesis.

The two cold air regime cyclogenesis patterns are: cold air vortex and induced wave. Cold air vortex developments occur frequently just off the West Coast and over the eastern U.S. Induced wave developments are observed more often east of the Rocky Mountains (and eastward).

Upper Air Flow Patterns (Figure 329):

Two sample upper air flow patterns are shown in Figure 329. These patterns occur with both types of cold air regime cyclogenesis. In these patterns, short wave disturbances and their accompanying jet stream systems (noted at S in both figures) move southeastward within the cold air towards the base of the main trough. Cyclogenesis occurs on the cold air side of the older or initially stronger jet baroclinic zone (short solid arrows in both figures), and it occurs within a generally confluent area of the large-scale flow pattern.

Both cold air vortex and induced wave cyclogenesis begin similarly as shown in the two sample illustrations (Figure 329). With cold air vortex types, a complete new cyclone forms behind the older baroclinic zone producing its own separate baroclinic zone and surface fronts. In induced wave cyclogenesis, however, the short wave disturbance which initiates cyclogenesis induces a wave on the original baroclinic zone. The main jet stream and frontal zone are those of the original baroclinic zone which have responded to the approaching short wave.

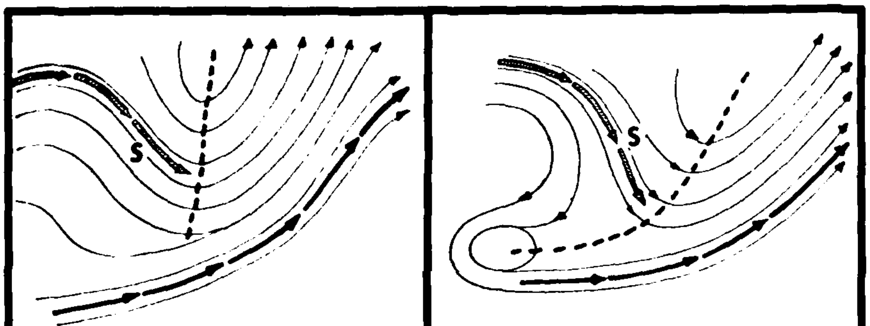

Figure 329: Two Sample Flow Patterns for Cold Air Vortex and Induced Wave Type Cyclogenesis

The rest of this section will discuss various stages of evolution of these two cold air cyclogenesis patterns. We will begin with cold air vortex cyclogenesis

Cold Air Vortex Cyclogenesis (Figures 330 through 333)

In the beginning of development, the dominant cloud pattern will be the old baroclinic zone cloud system located on the anticyclone side of a major trough. The baroclinic zone could be in the form of a long band of high and middle clouds along the jet-frontal zone of an elongated southwest-northeast oriented trough, or with a west-east oriented zonal flow. The baroclinic zone may still have some resemblance of an old, decaying comma cloud. The sequence of cloud development in cold air vortex cyclogenesis is:

- Vorticity Comma (B)
- Baroclinic Zone Cirrus (A)
- Deformation Zone Cirrus (C)

Phase 1 (Figure 330):

In the beginning of development, a "new" short wave and jet stream has entered the major trough circulation as noted by T in Figure 330. In Figure 330, the new jet axis is beginning to bend around the trough axis instead of joining with the older baroclinic jet system on the front side of the trough. The strongest winds are still upstream and are moving over the ridge. When the new jet begins to curve around and becomes parallel to the old jet (with a zone of weaker winds between the two axes), it is an indicator that cold vortex cyclogenesis is likely to develop. (Note: If the new and old jet streams merge, then induced wave cyclogenesis is likely to develop).

When a short wave disturbance that will initiate cyclogenesis is approaching the major trough axis, it will usually be evident in IR data as a pattern of middle clouds. Often these middle clouds will have a distinct well-defined northern edge which will be just to the right of the axis of maximum winds at cloud top level as shown in Figure 330.

In Figure 330, a single short wave is indicated. This, however, is not always the case - there may be several smaller short waves with less defined cloud systems moving down the back side of the major trough. As these cloud systems arrive on the east side of the trough axis, each seems to add more energy to the development, until finally, a well-defined comma pattern begins to form.

Phase 2 (Figure 331):

In the second phase the short wave middle cloud pattern has just arrived on the east side of the major trough axis (the axis becomes sharper and better defined as increased curvature forms there).

The short wave pattern begins to form the vorticity comma shape (B in Figure 331) with convection increasing over the comma and resulting in higher cloud tops (and heavier precipitation). A single surface low may not have organized yet; several lows may be evident within the surface trough north of the jet stream.

Phase 3 (Figure 332):

The new storm has begun to form the comma pattern. Considerable cirrus and cirrostratus has formed along the newer jet axis on the east side of the major trough (smaller A in Figure 332), however, the older jet axis and its cirrus deck remains further to the east. As the new storm intensifies and sharpens the amplitude of the upper level trough, the edge of the older cirrus deck will tend to become generally parallel to the new cirrus - especially along the cyclonically curved portion. There may still be smaller scale waves along the older cirrus edge, which are out of phase with the new system.

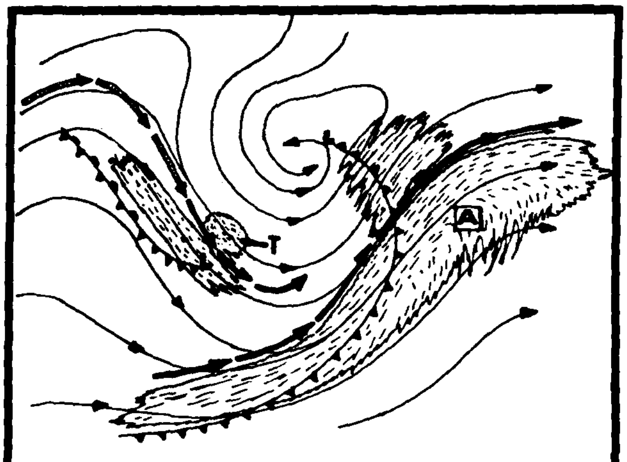

Figure 330:

First Phase in Cold Air Vortex Cyclogenesis

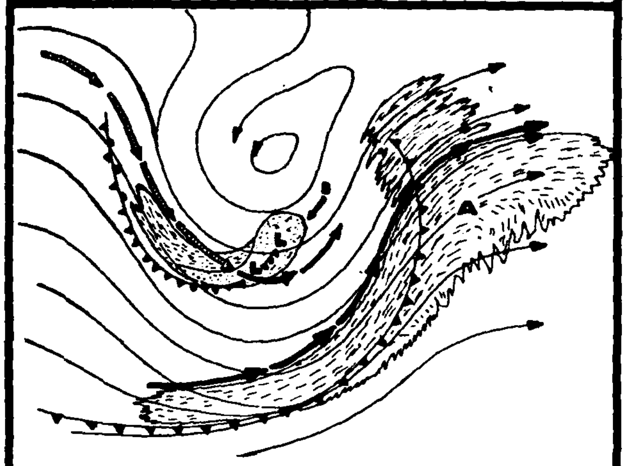

Figure 331:

Second Phase in Cold Air Vortex Cyclogenesis

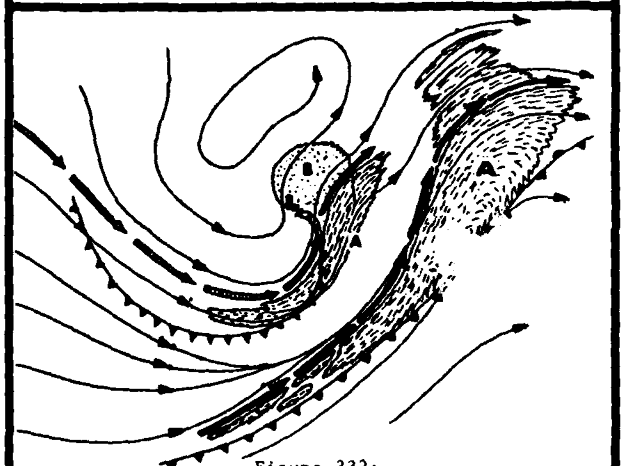

Figure 332:

Third Phase in Cold Air Vortex Cyclogenesis

Phase 4 (Figure 333):

In the final phase a complete new storm cloud pattern has formed behind (or on the cold side) of the old baroclinic zone. Usually, as the new system develops, the older jet baroclinic zone and its cloud system weakens primarily due to its cold air supply being cut off, and the development of warm moist air aloft in advance of the new system.

If the new cyclone continues to develop beyond this stage, it is likely that the new frontal zone will catch up to the old one in the south quadrant of the low. Eventually, the two frontal zones will merge into one.

The old baroclinic zone jet stream (eastern jet) will often weaken while the newer jet zone becomes dominant. These systems often develop into very intense Type B systems as illustrated earlier in Figure 312.

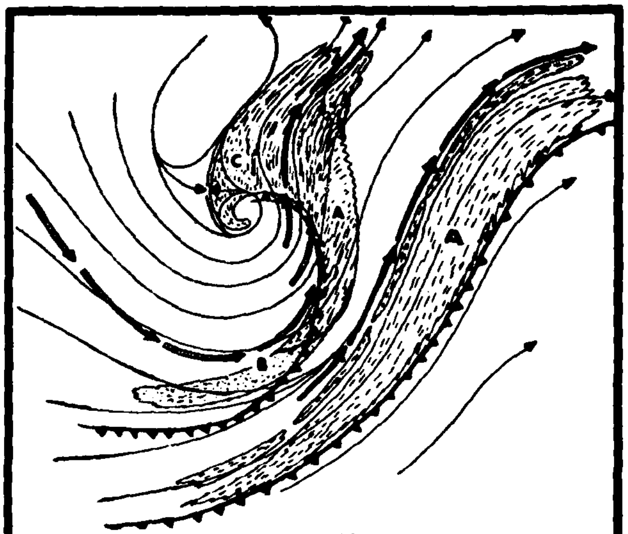

Figure 333:
Fourth Phase in Cold Air Vortex Cyclogenesis

Induced Wave Cyclogenesis (Figures 334 through 337)

Induced wave cyclogenesis occurs when a short wave disturbance moves within the cold air across the major trough and merges with the older baroclinic zone located on the east side of the major trough. As the middle cloud comma cloud pattern forms and approaches the older baroclinic zone, it will appear to induce a wave on it.

Of all the types of cyclogenesis presented, this last type is the most frequent form of development, and it has the least geographical preference. The sequence of development of the major cloud systems in an induced wave pattern are:

- Vorticity Comma (B)
- Wave on Baroclinic Zone (A)
- Deformation Zone Cirrus (C)

Phase I (Figure 334):

At this early stage, the pattern will be very similar to that of the cold air vortex development. The older jet zone cirrus (large A in Figure 334) is likely to be closer to the major trough axis - especially at the point where the new speed maximum and short wave is approaching the older zone as noted at R in Figure 334. The leading portion of the jet maximum coming over the ridge may appear to merge with the older jet axis, such that no double jet structure can be seen east of the trough axis.

In some cases, the leading part of the new jet will "turn the corner" and move up the east side of the major trough with two parallel jet axes present. When this kind of jet structure evolves, it is common to have a series of smaller scale disturbances moving along both jet zones. One series showing as middle clouds will move down the newer jet branch, and the other showing as perturbations in the older jet cirrus deck will be moving from the southwest. As the two streams merge closer together, the small scale disturbance of the two streams will usually be out of phase; if they are, development is deterred. When a pair of systems arrives in phase, development begins.

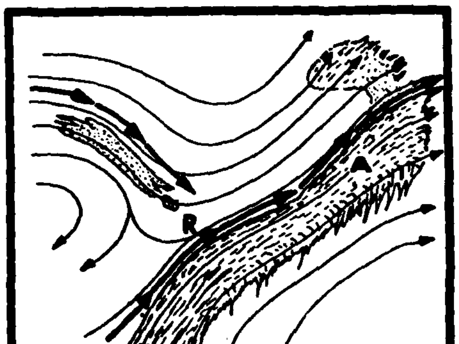

Figure 334:
First Phase
in Induced Wave Type Cyclogenesis

At other times, as in the case depicted in Figure 334, a single larger scale disturbance approaches the older baroclinic zone.

Phase 2 (Figure 335):

As the disturbance and the leading portion of the strong winds arrive at the major trough axis, a comma-shaped middle cloud pattern develops (B in Figure 335), often with convection and precipitation forming rapidly. Some higher cloud tops will likely form over the comma and develop a plume where the axis of maximum winds crosses the comma surge region.

The rear edge of the older baroclinic zone cirrus layer immediately begins to deform to the pattern of the developing comma.

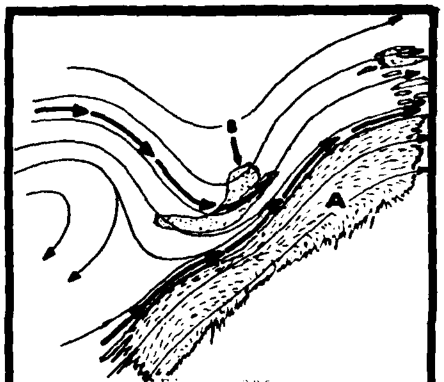

Figure 335:
Second Phase
in Induced Wave Type Cyclogenesis

Phase 3 (Figure 336):

By this time, the comma (B) has become better defined and grown larger, and the jet streams have merged into a single upper level baroclinic zone. The region of strong winds is likely to be wider in this area, but no jet structure can usually be found - either in the upper air network or in evidence of the cirrus.

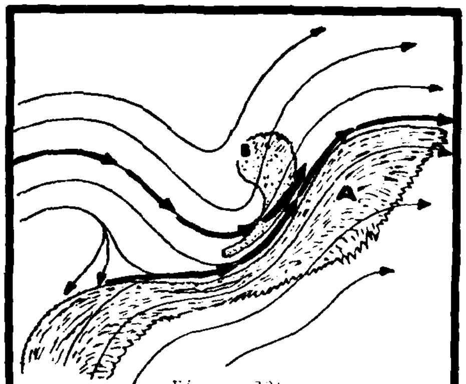

Figure 336:
Third Phase
in Induced Wave Type Cyclogenesis

Phase 4 (Figure 337):

In the previous phase, the comma tail was parallel to the western edge of the cirrus deck, but by the fourth phase, Figure 337, the comma has now rotated and the tail has moved under the cirrus deck. More cirrus has formed over the comma head - especially at the deformation region (C), and now a mature storm pattern has formed.

The clouds over the comma head near where the jet axis and cirrus edge crosses are likely to be lower than on the rest of the comma head.

In Figure 337, the comma tail is shown swinging around under the baroclinic zone cirrus with only the comma head showing. This action would be most likely when the storm system continues to develop to maturity; but, with many developments which do not go full cycle (and most don't), the comma tail may remain nearly parallel to the cirrus edge (out in the open west of the cirrus edge). In many cases, a well-defined comma pattern does not form, however, a region of irregular-shaped middle clouds shows at the position where the comma head appears in Figures 335 through 337.

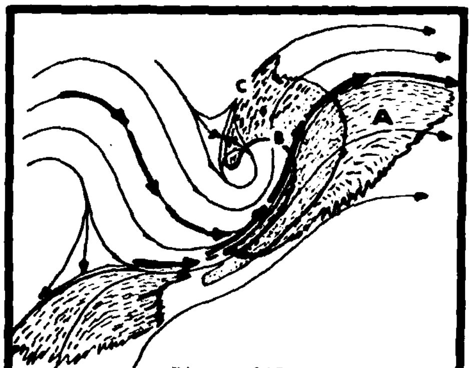

Figure 337:
Fourth Phase
in Induced Wave Type Cyclogenesis

Case Study (Figures [illegible] through [illegible]):

The following [illegible] satellite photos shows [illegible] cloud [illegible] [illegible] zone located [illegible] The [illegible] wave development [illegible]

The [illegible] and surface analyses are respectively shown in Figures [illegible] and [illegible]. In Figure [illegible], a long wave [illegible] system is shown; the short wave responsible for [illegible], which will be shown in subsequent satellite photos, is difficult to locate within the long wave flow. At the surface, frontal waving over Pennsylvania has begun.

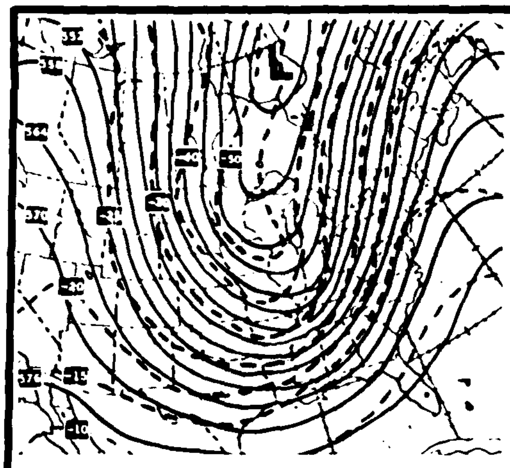

Figure [illegible]: 500MB [illegible] February 1981

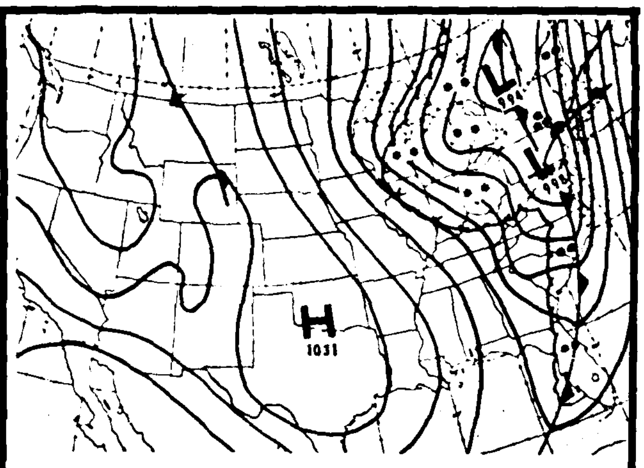

Figure [illegible]: Surface 1200Z [illegible] February 1981

[illegible] the stationary [illegible] zone [illegible] signs of induced waving as [illegible] located across eastern Pennsylvania and west [illegible] approaches the zone. [illegible] the [illegible] wind reports have been [illegible] the [illegible] cloud is beginning [illegible] the baroclinic zone cloud system. Area [illegible] level cloudiness.

Figure 340: 1425Z 2 February 1981

Figure 341: 1515Z 2 February 1981

Several hours later, Figure 342, nearly half of the comma system (B) has moved under the cirrus deck. Finally, in Figure 343, only the western end of the comma system (B) is visible in the photo. This system continued to develop, moved northward, and became a mature storm system over eastern Canada within 24 hours.

Figure 342: 1846Z 2 February 1981

Figure 343: 1916Z 2 February 1981

It has been shown in both types of cold air regime cyclogenesis that the comma cloud associated with the short wave disturbance crossing the cold air, is primarily a middle level cloud system. Often, over the oceans, and especially with induced wave cyclogenesis, the "new" short wave will appear as an area of deeper convection embedded within the general cold advection cumulus field (enhanced cumulus). These enhanced cumulus areas reflect a PVA area and often initiate cyclogenesis along the baroclinic zone. An example was shown earlier in Figure 243, page 60.

In this section several more cyclogenesis events which occur over the central and eastern U.S. will be shown. The basic cloud systems that were discussed in previous sections will probably be recognizable, however, each system's structure and development is different.

Case Study 1 - Cyclogenesis along the East Coast:

Forecasters located over the eastern U.S. should pay particular attention to the actions of decaying, vertically-deep low systems which "hang up" over the Great Lakes area. Often, new frontal cyclogenesis occurs along the eastern seaboard or offshore (generally triple point development) as the old low system dies. An apparent transfer of energy evolves to the new system where the baroclinic zone strengthens due to stronger temperature, moisture and wind discontinuities. These new disturbances can mature quickly into major cyclones - nor'easter events are not unusual with this pattern.

The 500mb and surface analyses are respectively shown in Figures 344 and 345 several hours prior to the satellite photos. In Figure 344, a closed low appears over the Great Lakes area; the strongest wind field reflecting the polar jet stream lies well to the south of the low system. A negative-tilt trough extends from the low southeastward to Florida - often this type of short wave trough orientation across the southeastern U.S. breeds intense cyclones. The related surface analysis shows a disorganized low pressure pattern across the eastern U.S. The Illinois low stacks with the upper low; a weak frontal low appears offshore. Widespread light snowfall is occurring within the two systems.

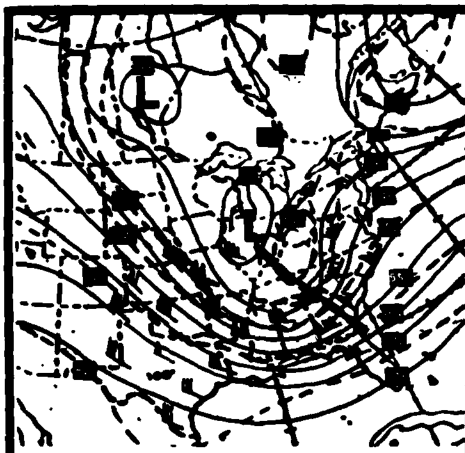

Figure 344:

500MB 1200Z 6 February 1980

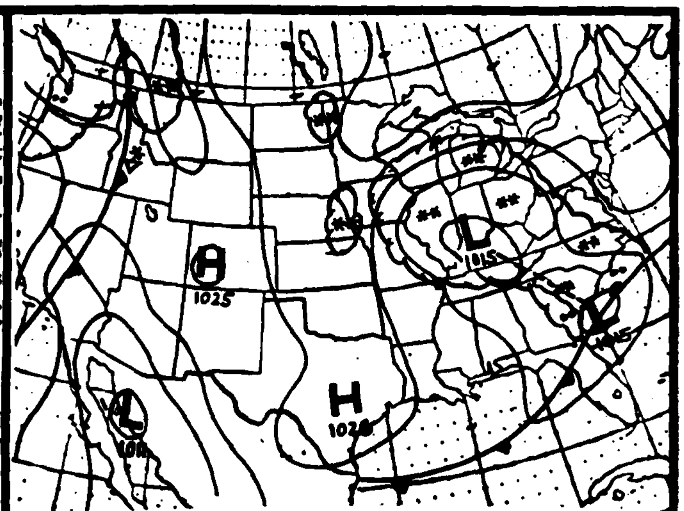

Figure 345: Surface 1200Z 6 February 1980

The enhanced IR photo several hours later, Figure 346, reveals that the highest tops cover a large area across Virginia, North Carolina and offshore (see arrow). This area is the strengthening baroclinic zone; the old decaying low system, indicated by the white L, shows lower (warmer) cloud tops.

Figure 346: 1446Z 6 February 1980

In the related visible, Figure 347, approximately two hours later, shadows help reveal the baroclinic zone structure (A) and the highest cloud tops. Heavier precipitation would be occurring under cloud system A; precipitation would also be occurring in the lower cloud systems over the Ohio Valley - Great Lakes area, but intensities would be lighter than in cloud system A.

It is emphasized again that when a cloud system such as shown at A in Figures 346 and 347 appears in that general location, an intensified METWATCH must be initiated for locations from Virginia northward into New England. Figure 348 depicts the surface pattern the following morning. Indeed, an intense cyclone did develop; fortunately, for East Coast forecasters, this system intensified far enough offshore to keep severe winter weather away from the mainland.

Figure 347: 1616Z 6 February 1980

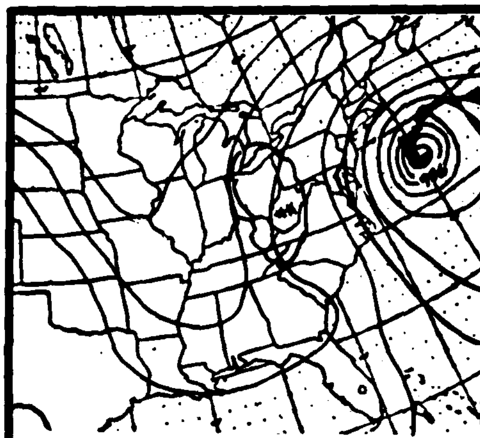

Figure 348: 1200Z 7 February 1981

Case Study 2 - Cyclogenesis along the Gulf Coast:

During the cold season, large areas of cloudiness, located over the central and southern U.S., may persist for several days or more. Generally, an extensive zone of stagnant high pressure (polar air) lies across the central and northern U.S. and Canada. Consequently, storm tracks are shifted southward across the southern U.S., Mexico and the Gulf of Mexico. Forecasters, located along the storm track, should look for telltale signs of system development in satellite photos. Several indications have been discussed in this TN such as "V" notches and "S" shape cloud systems which reflects jet stream maxima. The following three photos illustrate the development of a southern storm system.

In Figure 349, the three primary cloud systems are noted. The vorticity comma cloud (B) is partially hidden under the baroclinic zone cloud system (A). Seven hours later, the IR photo, Figure 350, shows a notch (noted by the arrow) on the western side of the cloud system. The notch reflects a jet stream maximum which propably will initiate cyclogenesis. In the visible picture the following day, Figure 351, a large disturbance has evolved. Significant precipitation occurred over a large area from the Gulf of Mexico to the Ohio Valley.

Figure 349: 1631Z 19 January 1981

Figure 350: 2330Z 19 January 1981

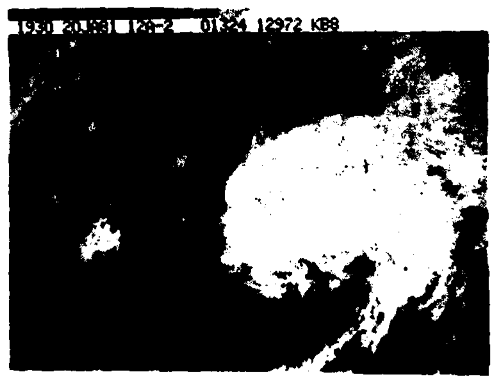

Figure 351: 1930Z 20 January 1981

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7. AWS-TR-76-264, Satellite Meteorology, August 1976.

INDEX

Errata - 3WW/TN-81/001, 28 Dec 1981 29 January 1982

The following errors have been noted. Corrections, in the form of page changes, will be forthcoming.

Page 36, Figure 146: Photo in backwards.

Page 69, Figure 278: Photo should be shown in Figure 279's location and vice-versa.

Pen and Ink change: Page 67, Figure 271: Change time and date to read: 1830Z 16 July 1981.

Note: Several pictures are either too bright or too dark; we will attempt to improve these pictures with subsequent page changes.

CORRECTION - PAGE 15

Cumulus - Open-cell cumulus cloud shapes are even better for determining surface and lower-level wind speeds. Figure 54 depicts various stages of open-cell cumulus with respect to wind speeds. If the cells are circular shape, then the winds are less than ten knots (Figure 54a). When they start to become oval shape, the winds are between ten and twenty knots (Figure 54b). When the cells become horseshoe shaped, the surface winds are between twenty and thirty knots (Figure 54c). Finally, when the cells become severely elongated (Figure 54d), the winds are greater than thirty knots. In Figure 55, an enhanced IR, horseshoe-shaped, open-cell cumulus are recognizable within the cold, cyclonic flow of a Great Plains storm system (see related visible photo, Figure 50).

DATE

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